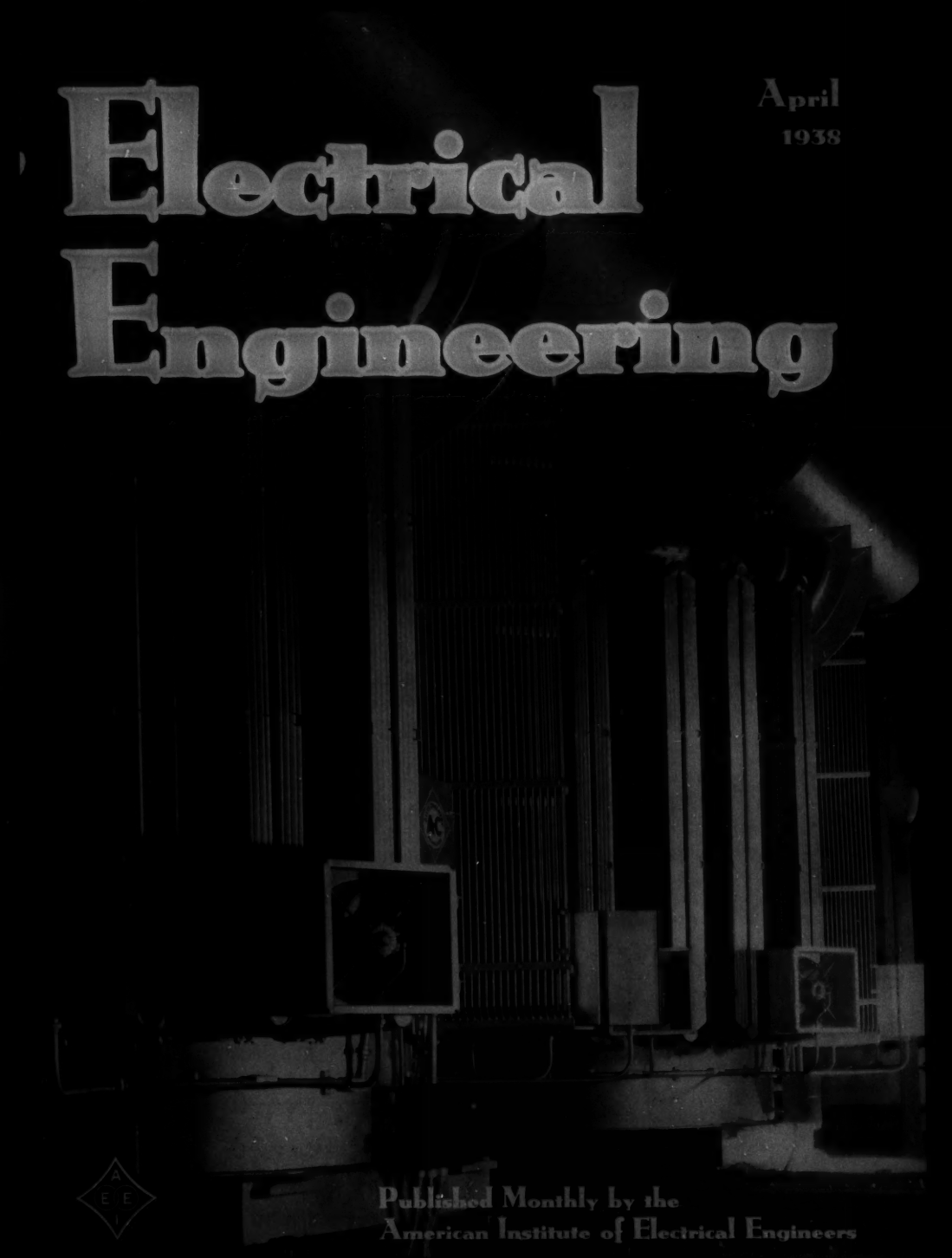
Electrical Engineering

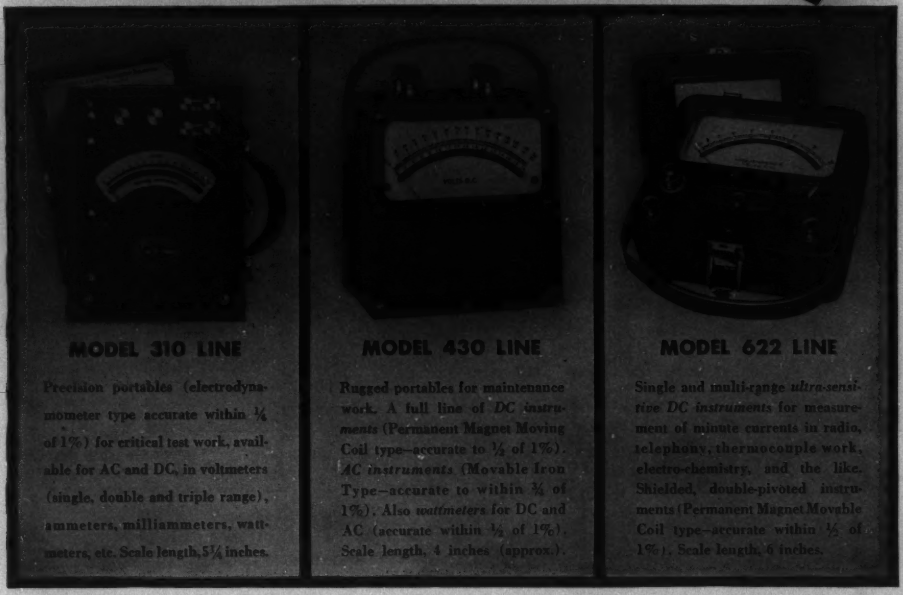
April
1938



Published Monthly by the
American Institute of Electrical Engineers

Trustworthy

. . . For Every Test Requirement



MODEL 310 LINE

Precision portables (electrodynamometer type accurate within ¼ of 1%) for critical test work, available for AC and DC, in voltmeters (single, double and triple range), ammeters, milliammeters, wattmeters, etc. Scale length, 5¼ inches.

MODEL 430 LINE

Rugged portables for maintenance work. A full line of *DC instruments* (Permanent Magnet Moving Coil type—accurate to ½ of 1%). *AC instruments* (Movable Iron Type—accurate to within ¾ of 1%). Also *wattmeters* for DC and AC (accurate within ½ of 1%). Scale length, 4 inches (approx.).

MODEL 622 LINE

Single and multi-range *ultra-sensitive DC instruments* for measurement of minute currents in radio, telephony, thermocouple work, electro-chemistry, and the like. Shielded, double-pivoted instruments (Permanent Magnet Movable Coil type—accurate within ½ of 1%). Scale length, 6 inches.

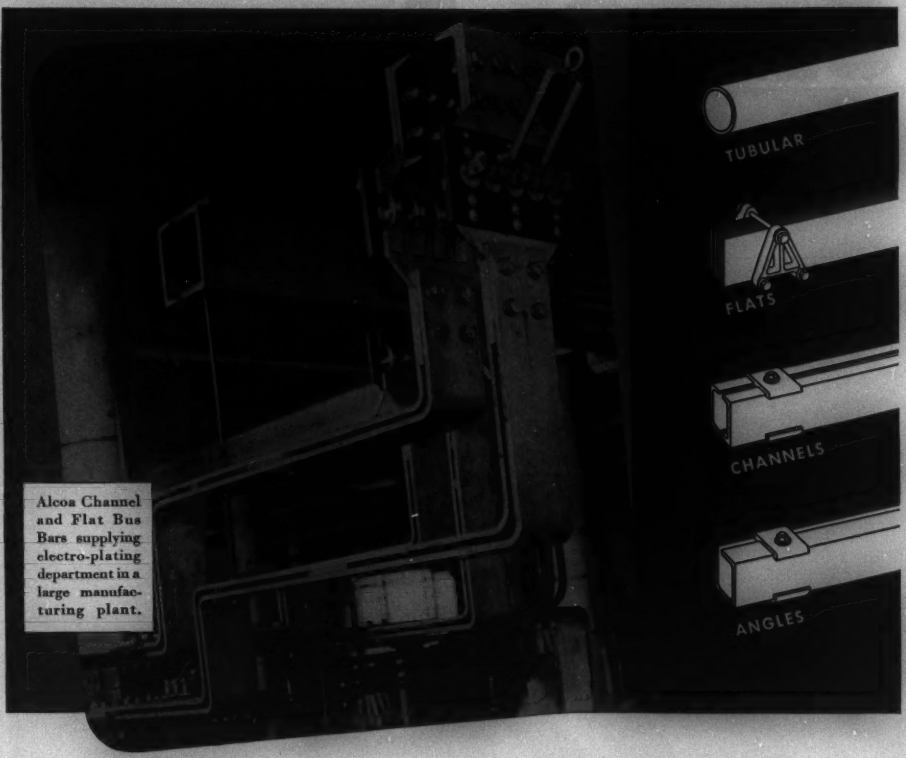
For maintenance work, for industrial or school laboratories—wherever portable test instruments are employed—the name WESTON is recognized as a symbol of trustworthy electrical measurement.

WESTON "Portables" are designed in several types, with specifications and ranges to meet the particular requirements of all varieties of test work. Behind all the specifications, however, is the same "engineering-from-bedrock"—a consistent application of the design factors that make for rugged dependability as well as rated accuracy.

After all, when you buy a WESTON—whatever the type or specifications—you get an extra increment of experience which stems from a half-century of instrument building. Why not check with the WESTON representative as to the type of meter best suited to your needs?

Weston Electrical Instrument Corporation, 664 Frelinghuysen Avenue, Newark, New Jersey.

WESTON *Instruments*



Alcoa Channel and Flat Bus Bars supplying electro-plating department in a large manufacturing plant.

MEETING ALL OF YOUR REQUIREMENTS

Alcoa Aluminum Bus Bar

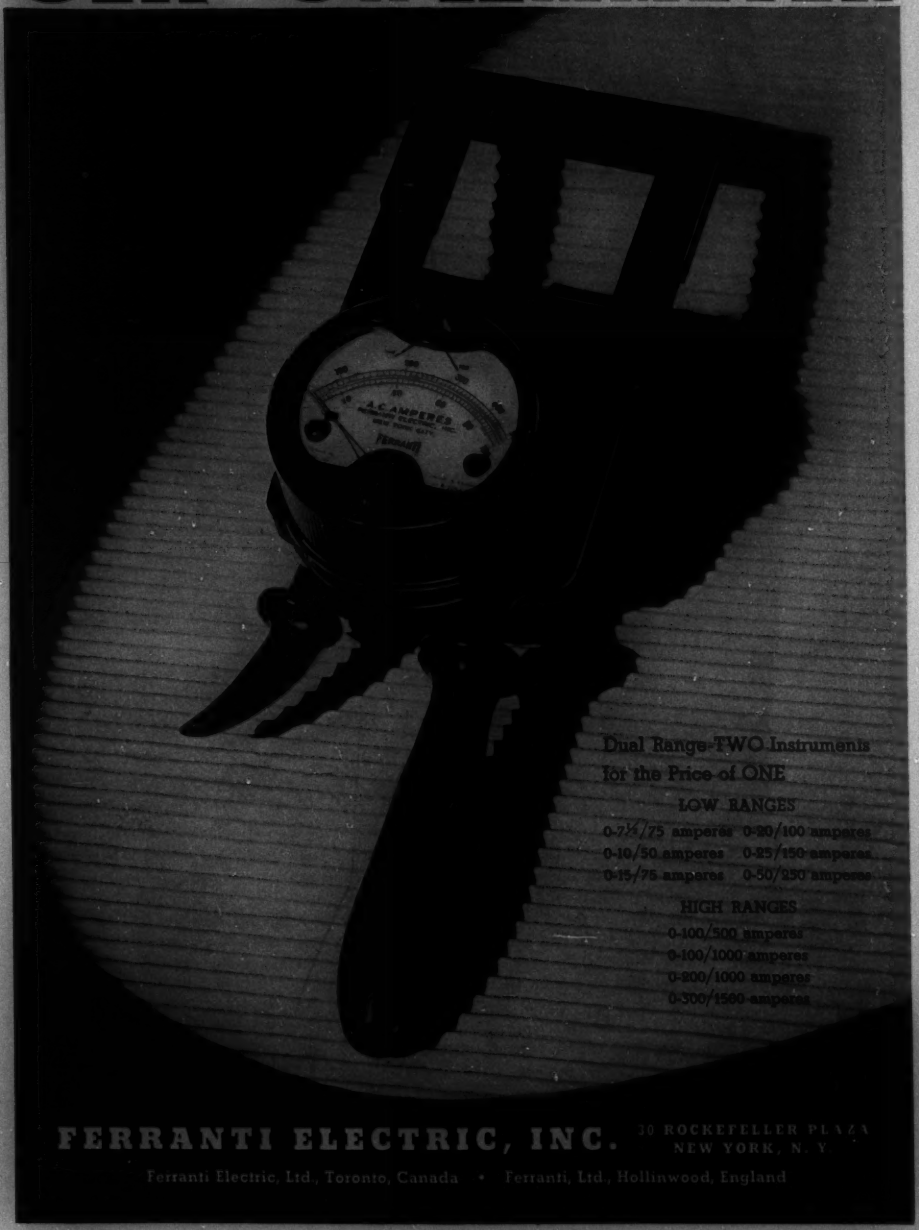
For heavy-current buses like the installation pictured above, for inside or outdoor substations, for power distribution in commercial buildings and factories; no matter what the character of the installation, there is an Alcoa Aluminum shape suitable for your use.

Extremely light in weight, Aluminum Bus Bars place a minimum strain on supporting structures. They are easy to handle in erecting. Readily formed, Aluminum buses can be tailored to suit each layout. Joints are made by bolting or welding. Fittings for every purpose are available; costs are low.

Alcoa Aluminum Bus Bar comes in any desired form: Flats, tubes, angles, channels, etc. Rolled channel or angle sections offer the highest combination of electrical, thermal and mechanical efficiency. We shall gladly send you data on each type. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh, Pennsylvania.

ALCOA ALUMINUM

CLIP-ON AMMETER



FERRANTI ELECTRIC, INC. 30 ROCKEFELLER PLAZA NEW YORK, N. Y.

Ferranti Electric, Ltd., Toronto, Canada • Ferranti, Ltd., Hollinwood, England

Electrical Engineering

Registered U. S. Patent Office

for April 1938—

Science and the Future of Aviation	...Igor I. Sikorsky	...149
New 98-Inch Continuous-Strip Steel Mill Opened		...154
European Switchgear Developments	...D. C. Prince	...155
Some Observations on Economics, Politics, and Government	...James D. Mooney	...164
Determination of the Cause of Sheath Corrosion	...W. G. Radley	...168
Converting 2.3-Kv Feeders to 4-Kv Operation	...E. R. Coop and O. E. Sawyer	...172

Miscellaneous Short Items: Electrification of French Railways, 167——A New Swiss Lake, 175

News of Institute and Related Activities (See next page) ...176

*Transactions Section—Papers and Correlated Discussions** *(Follows EE page 190)*

Sharp Cutoff in Vacuum Tubes—Slide-Back Voltmeter	...C. B. Aiken and L. C. Birdsall	...171
Interpretation of Oscillograms of Welding Generators	...K. L. Hansen	...177
Co-ordination of Power Transformers	...V. M. Montsinger	...183
Distribution Transformer Lightning-Protection Practice	...L. G. Smith	...196

* For discussions of previously published papers, see next page.

VOLUME 57 NUMBER 4

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

W. H. HARRISON, President H. H. HENLINE, National Secretary

PUBLICATION COMMITTEE—I. Melville Stein, *chairman* J. W. Barker O. W. Eshbach H. H. Henline L. W. W. Morrow A. G. Oehler H. S. Osborne H. S. Phelps D. M. Simmons M. W. Smith W. H. Timbie

—— PUBLICATION STAFF ——

G. Ross Henninger, Editor F. A. Norris, Business Manager
Floyd A. Lewis, Associate Editor C. A. Graef, Advertising Manager

Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

The Cover

A bank of three-winding power transformers with forced air cooling

Photo courtesy Allis-Chalmers *Electrical Review*

High Lights

Discussions. This issue marks another step in the transition from the publication policy in effect during the years 1934–37 to the new plan adopted this year. In the TRANSACTIONS Section, all papers are published with correlated discussions. Discussions on some previously published papers still remain to be published; discussions of three such papers are included in this issue; others will appear in early issues. When the transition is complete, *all* discussions will be correlated with their respective papers.

Science and the Future of Aircraft. Within a few years, passengers will cross the Atlantic in less than 20 hours on 100-ton flying boats. Practical considerations probably will limit aircraft operating speeds to between 200 and 300 miles per hour during the coming decade, but a certain increase in speed may be expected from operating at high altitudes. These are some of the predictions made by a noted aviation authority (*pages 149–53*).

Co-ordination of Transformers. To co-ordinate or protect transformers intelligently for all kinds of impulse waves requires an accurate knowledge of the volt-time characteristics of transformer insulations. Laboratory tests made to determine these characteristics, based upon the effect of both single and repeated applications of impulse voltages on both the corona voltage level and the breakdown, are reported in a paper in this issue (*Transactions pages 183–95*).

Lightning Protection. Several different arrangements are used to protect distribution transformers from lightning damage; a comprehensive collection of data for various kinds of distribution-transformer failures caused by lightning in many widely scattered locations and of different voltage classes seems to indicate that solid interconnection in which the arrester ground lead is interconnected with the secondary neutral reduces failures (*Transactions pages 196–220*).

Oscillograms and Welding Performance. An arc-welding generator supplies energy to a load in which conditions are continually changing; consequently, the so-called "transient" performance is more important than the static, or steady-state, performance of the machine. The transient or dynamic voltage-current curves of welding generators as determined by oscillograms are discussed in this issue (*Transactions pages 177–82*).

Economics, Politics, and Government. Some observations on economics, politics, and government have been made by an engineer who has had an opportunity to study governments in various parts of the world for the last 20 years. One important observation is: "that the trend of many governments today . . . is . . . toward too . . . great a control over every area of the lives of men" (*pages 164–7*).

Summer Convention. Committees are busy planning the program of the AIEE 1938 summer convention to be held in Washington, D. C., June 20–24. Tentative plans call for 1 general session, 11 technical sessions, and 5 technical conferences, with the usual flavor of entertainment and sport features and interesting trips to points of interest in this historical center (*page 178*).

Slide-Back Voltmeter. Peak values of small alternating voltages may be measured accurately by the use of a slide-back voltmeter (a kind of vacuum-tube voltmeter) employing a tube having a steep current-voltage curve and the application of a correction factor (*Transactions pages 171–6*).

Conversion From 2.3 to 4 Kv. Because such a project usually involves a large area, the many details involved in converting distribution feeders from 2.3- to 4-kv operation must be co-ordinated accurately by a definite system of planning. One successful method of procedure is outlined in this issue (*pages 172–5*).

News 176

North Eastern District Meeting 176
AIEE Section Organized at Muscle Shoals 177
Report on Telemetering Now Being Revised 178
Summer Convention to Be Held in Washington . . . 178
A Pacific Coast Convention Attraction 179
AIEE Atlanta Section Becomes Georgia Section . . 179
To Institute Members Planning Trips Abroad 179
Future AIEE Meetings 178
Future Meetings of Other Societies . . 180
Letters to the Editor 182
The Dielectric Circuit 182
Registration of Engineers 182
Pareto—Engineer, Economist, Sociologist 183
American Engineering Council 181
Standards 182
Personal Items 184
Membership 188
Engineering Literature 190
Industrial Notes . . . . . (See advertising section)
New Products . . . . . (See advertising section)
Employment Notes . . . . (See advertising section)
Officers and Committees (For complete listing see pages 1217–21, September 1937 issue)

North Eastern District Meeting. A tentative technical program has been announced for the AIEE North Eastern District meeting to be held May 18–20, 1938, at Lenox, Mass. The meeting program will include entertainment, sight-seeing trips, and inspection trips to nearby industries (*pages 176–7*).

Pacific Coast Convention. Dates for the AIEE 1938 Pacific Coast convention, August 9–12, to be held in Portland, Ore., are almost a month earlier than usual in order to provide a better opportunity for combined vacation-convention trips (*page 179*).

Corrosion of Lead Sheath. Before measures to protect the lead sheath of underground cables from corrosion can be planned, the cause of the corrosion must be known. Several methods of determining the cause are in use (*pages 168–71*).

European Switchgear. Wide differences exist in the design of switchgear for electric-power systems between the United States and European countries; the latter depend largely on circuit breakers containing little or no oil (*pages 155–63*).

Coming Soon. Now undergoing preparation for publication in early issues are the following: An article on radioactivity by K. K. Darrow, noted writer on physical subjects; four papers on a carrier telephone system for toll cables and related problems and equipment by nine Bell-System engineers—C. W. Green, E. I. Green, R. W. Chesnut, L. M. Ilgenfritz, A. Kenner, C. E. Lane, M. A. Weaver, R. S. Tucker, and P. S. Darnell; a paper on modern city transportation by E. J. McIlraith; two papers on nonlinear circuits of the "ferro-resonant" type, by I. A. Travis and C. N. Weygandt, and P. H. Odessey and Ernst Weber; a paper on electronic speed control of motors by E. F. W. Alexanderson, M. A. Edwards, and C. H. Willis; and a paper describing a method of preventing the operation of differential relays on unbalanced currents not resulting from faults, by L. F. Kennedy and C. D. Hayward.

DISCUSSIONS

Appearing in this issue are discussions of the following previously published papers:

Electric Welding

The Rating of Resistance-Welding Transformers—Heitman **221**
Recent Advances in Resistance Welding—AIEE Subcommittee Report **225**
An Electronic Arc-Length Monitor—Richter **226**

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*; and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

¶ Copyright 1938 by the American Institute of Electrical Engineers.

Number of copies this issue—22,300.

Science and the Future of Aviation

BY IGOR I. SIKORSKY

IN ANALYZING the probable future trend in the development of aviation, it appears desirable to limit the discussion to the study of three major factors, the combined effect of which to a large extent will determine the most interesting future developments. The characteristics under discussion will be speed, altitude of flight, and possible size of aircraft.

Speed

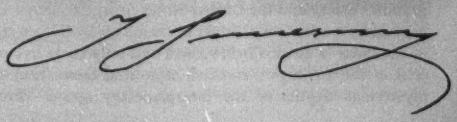
The possibility of traveling at great speed is the major reason for flying. A study of this factor and its future development is, therefore, of particular interest. The progress that has been made in this respect may be seen from table I, which includes some of the world records established between 1909 and the present time.

The present record of 440.62 miles per hour, or 646 feet per second, is equal to about one-half of the velocity of an average revolver bullet. Traveling at such speed, one would reach Times Square in New York City in about 19 minutes after leaving Schenectady, N. Y. A heavy load dropped from the top of the Empire State Building, which is about 1,200 feet high, would reach the pavement at a velocity less than one-half that of this aircraft even if the resistance of the air is disregarded. In order that

Travel by air is now a well-established method of communication. It is no longer an event to board an airliner in New York with air passage to Rio de Janeiro, or to Hongkong, and from there to fly further along established airlines to Europe, Africa, or Australia. The highly interesting and romantic pioneering period of aviation appears to have been concluded by a series of important achievements, the last of which was the establishment of regular transoceanic air service by the American flying clipper ships.

Aviation by now is a valuable factor in national life. It is an important branch of the armed forces. A vital factor in civil transportation, it is guided by several new sciences, special literature, scientific research, and educational institutions, and is served by a young but already well-established industry. It is strange to remember and to realize that only 30 years ago all this was not in existence. World aviation was represented by a few individual pioneers who were pushing the new art of flying ahead against considerable odds. A modern engineer would have difficulty in imagining the working handicaps of the pioneer pilot-designer of aircraft, who had to develop and build his machines with no reliable information available except the results of primitive, homemade research equipment, the study of the birds, and to a great extent the products of his imagination guided by intuition, knowing that an incorrect assumption or unfortunate guess might result in the loss of his flying machine and even of his life.

Comparing the modest performances of the early flying machines and the almost complete lack of reliable scientific data in 1908 with the present situation, we can realize the remarkable progress that has been made in the aeronautical industry and science during the short period of one generation. I believe it to be appropriate to mention these few ideas by way of a tribute to the work of pioneers in aeronautical science and engineering at a forum dedicated to the memory of an outstanding engineer who contributed greatly to the progress and development of one of the most important of modern industries.



Essentially full text of the twelfth Steinmetz Memorial Lecture delivered under the auspices of the Steinmetz Memorial Foundation at a meeting of the AIEE Schenectady, N. Y. Section on March 3, 1938.

IGOR I. SIKORSKY is a native of Kiev, Russia, and received his technical training at Petrograd, Paris, and the Polytechnic Institute at Kiev. In 1908, at the age of 19, he built his first aircraft, a helicopter. In 1910 he started building airplanes, and the following year two of his ships flew as long as one hour and reached an altitude of 1,500 feet. From then on he gained recognition, receiving awards in aviation exhibitions and competitions. He foresaw the necessity of large, multimotored flying ships and built the first successful one. Until 1917 he built planes for the Russian government, and following the revolution he was in France where he was commissioned to build planes for the French government. In 1919 he came to the United States, and later formed the Sikorsky Aero Engineering Corporation. This organization and its successor built single-motored and multimotored planes for commercial transport and government use. The first successful amphibian was developed in 1927. In 1929 the Sikorsky company and the United Aircraft and Transport Corporation were merged and the present factory built at Bridgeport, Conn.

the velocity of this airplane would be reached by a falling body, a drop from about 6,400 feet would be necessary, again disregarding the resistance of the air.

Such speed cannot be expected to be introduced in practical operation within the near future. The operating speed of the latest types of modern air transports, which is about 200 miles per hour for a landplane and about 160 miles per hour for a long-distance flying boat, is already very satisfactory. This speed is respectively about four times faster than the best railroad train from point to point, and six to seven times faster than the latest steamship. While this appears to be sufficient to justify travel by air, yet a further increase in operating speed must be expected, although a very high speed would be uneconomical and in many respects inconvenient. Practical considerations probably will limit the operating speed to a figure between 200 and 300 miles per hour during the coming decade. A certain increase in speed may be expected from operating at high altitudes. This factor will be discussed in greater detail in connection with stratosphere flying.

The table of the speed records established by airplanes shows that the greatest velocity of flying was increased more than nine times during the last 30 years. In line with this, various predictions have been made that in the coming 25 years velocities in excess of 1,000 miles per hour could be expected at low or high altitudes. In view of the present knowledge of aeronautics, this does not appear to be the case. Recent investigators have discovered that a great change in the character of streamline flow around the wing occurs when the speed reaches or approaches the velocity of sound, which is about 760 miles per hour at sea level. The adverse effects begin to be pronounced even at much lower speeds, usually around 500 miles per hour. The disturbance of the flow results in a considerable increase in the resistance of the moving body. Because flight above 400 miles per hour will necessitate expenditure of considerable power even under the best possible conditions of streamline flow, and because propeller efficiency has a tendency to fall off when the velocity of 500 miles per hour is exceeded, this speed may prove a practical limit for a substantially long time. Although extreme engineering effort and further research possibly may improve these figures, it appears quite certain that the present greatest speed will not be doubled unless new methods of generating power which permit the utilization of much greater energy within a given size and weight of airplane become available.

Altitude

The present world altitude record, established in 1935 by Captain O. A. Anderson and Major A. W. Stevens in a stratosphere balloon, is 72,395 feet. During this outstanding flight, which was sponsored by the National Geographic Society and the United States Army Air Corps, the aeronauts reached an altitude at which about 95 per cent of the mass of air was below them and only some five per cent of the air, highly rarefied, separated them from the mysterious depths of the interplanetary space. From this altitude they could observe and photograph the curvature of the earth. They were able to bring back a rich cargo of scientific data relating to air pressure, temperatures, electrical conductivity, cosmic rays, and infrared photography.

The highest altitude reached by an airplane is 51,361 feet, which was achieved by Mario Pezzi of Italy in a Caproni plane on May 8, 1937. The practical altitude of transport flying at the present time is limited not by

Table I. Speed Records

Date	Place	Pilot	Speed (Miles per Hour)
1909	France	Curtiss	47
1919	United States	Rohlfs	162
1929	England	Orlebar	357
1934	Italy	Agello	441

the characteristics of the machine, as it was a few years ago, but chiefly by the ability of the occupants to withstand the effects of the rarefied air. Therefore, although most of the modern airliners could exceed altitudes of 20,000 or even 25,000 feet, the flight operation is limited to an altitude of not over 12,000 or 15,000 feet. The normal pressure at sea level is 2,116 pounds per square foot. It may be safe to consider that a person of any age in reasonable health may stand without discomfort an altitude at which the pressure and density would be about two-thirds of the normal. This would be at an altitude of 10,500 feet. According to the condition of physical health, difficulties would begin at an altitude that would bring the pressure somewhere between two-thirds and one-half the normal. Below one-half the pressure and density, the living conditions would be hard and detrimental to nearly every human being. A pressure of one-half the normal occurs at 18,000 feet; therefore, for flights above this altitude, air conditioning definitely becomes necessary. Although physically strong people may stand this and even higher altitudes by breathing oxygen, this is not convenient for general use and the best way would be to supercharge the cabin and to maintain conditions of satisfactory temperature, pressure, humidity, and chemical content by artificial means. Therefore, for carrying passengers at high altitude, all these conditions must be created artificially in a satisfactory and reliable way.

Power-plant requirements for high-altitude flying involve a series of independent, important problems. The major of them is the supercharging of the engine itself, which means that an air compressor of adequate power must be combined with the engine and must supply air under pressure in the intake manifold so as to maintain sea-level conditions. After this is done, it becomes possible to maintain the desirable engine power at much higher altitude as long as the supercharger will supply air under the necessary pressure. The other problem is that of cooling. Although at high altitude the air is generally very cold, the loss of efficiency of the cooling system produced by the low density of air is much greater than the

gain resulting from the low temperature. Another difficulty is with the gasoline supply. The low pressure outside is liable to reduce the boiling point of the fuel to such an extent that rapid evaporation may result in a great loss. To prevent this, pressure must be maintained in the gasoline containers, which necessitates much heavier tanks and in general is undesirable. Still another problem is connected with the propeller. It is easy to realize that the propeller that will be satisfactory in size and diameter for operation at sea level conditions cannot be the proper one for flying in air of considerably reduced density. According to the conditions, part of the efficiency at low or at high altitude must be sacrificed or a compromise made.

In spite of the difficulties that are outlined, the construction of a practical stratosphere aircraft is now a routine engineering problem that can be solved, but it will increase the weight of the aircraft, as well as its cost and the expenses of operation. Therefore, although there is no doubt that high altitude aircraft will be built and introduced in service in the very near future, only practical experience will determine how large a fraction of the total air traffic will go in the stratosphere.

These requirements necessitate the development of what is called a stratosphere airliner, an airplane with an enclosed airtight cabin properly supercharged which will permit compressing the air and maintaining reasonable internal pressure that will make the conditions comfortable for the occupants. It is generally accepted that the air pressure that would correspond to an altitude of from 8,000 to 10,000 feet is satisfactory and the problem for the designer, therefore, becomes to supercharge the cabin to such an extent so as to create such conditions. That would mean that if an aircraft were to be operated at an altitude of 25,000 feet, the pressure of the air outside would be 785 pounds per square foot, while inside it would have to be maintained at 1,572 pounds per square foot. These figures disclose that the problem of supercharging the cabin is not an easy one because every square foot of the cabin would have to withstand a pressure of 787 pounds; therefore, any window of average size would have to withstand one or more thousand pounds, while even the minimum-size door would have to withstand a pressure of 12,000 pounds. The difficulty would be greater if a still higher operating altitude were to be maintained. The airtight cabin must be made very reliable because a quick loss of pressure created by a broken window or similar damage would involve serious results even at 25,000 feet and would most probably be fatal to everyone on board at 35,000 feet or higher.

After discussion of the difficulties, a brief study of the advantages offered by the operation of aircraft at high altitudes appears desirable. They are, mainly, a certain increase in speed and the possibility of flying above most or all of the major weather disturbances. With reference to the increase in speed, there is no general rule that could be applied to determine all cases. The cruising performance of an *S*-43 amphibian at various altitudes calculated on the basis of using a constant power of 540 brake horsepower from each of the two motors is as follows:

Altitude in thousands of feet	0	10	20	30	35	40
Cruising speed (gross weight 20,000 pounds)	160	175	189	204	210	210

This may serve as an illustration of a particular case. In other cases, the variation of speed may be greater or smaller according to the characteristics of the aircraft.

Still more attractive is the other advantage, namely, the possibility to fly always in clear air above thunderstorms, fogs, and ice formations. Although bad weather in general is no longer a source of danger, operation in the always clear and reasonably smooth upper atmosphere would add to the comfort and to the accuracy of schedule which is very important. With these advantages and the possibility of approaching and eventually exceeding speeds of 300 miles per hour, without the use of excessive engine power, a real service test of airline operation at high altitudes is very desirable and can be expected in the near future.

Besides its application for air transport, high-altitude flying in itself presents substantial interest from a military and scientific standpoint and it appears proper to discuss briefly what can be achieved in this direction. There is no doubt that present altitude records will be substantially exceeded with further progress in the design of aircraft and their power plants. The evidence on hand, however, appears to indicate that somewhere between 75,000 and 100,000 feet may be the limit of altitude which most probably will not be exceeded by an airplane driven by an internal combustion engine and propeller. The reason for this is briefly as follows.

An airplane with cabin superchargers and all necessary equipment can hardly be produced so as to have an economic speed of less than 50 miles per hour at sea level. Even this speed would necessitate very light wing loading and therefore proportionately large wings. At the ex-

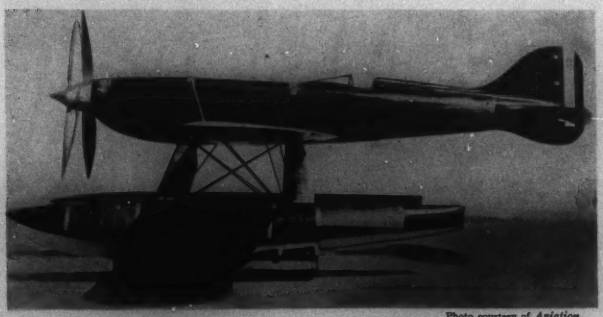


Photo courtesy of *Aviation*

Macchi Seaplane which, with 3,500-horsepower Fiat power plant, set a world's speed record of 440.681 miles per hour on October 23, 1934

treme figure of 100,000 feet, the density of the air is found to be about one one-hundredth of that at sea level, which means that it would be necessary to fly ten times faster or about 500 miles per hour to stay in the air at this altitude. This speed is too high for the efficient operation of the wings. Besides, the operation of a propeller with any satisfactory efficiency cannot be expected if such a great difference in density is experienced. Therefore, it is probable that an altitude of from 75,000 to 90,000 feet and a speed of from 500 to 600 miles per hour will not be exceeded until a new source of energy giving greater power per unit of weight, combined with a new method of propulsion, becomes available.

Size of Aircraft

Just 25 years ago, in March 1913, the author was finishing the Sikorsky *S*-21, the first four-engined airplane, which had a gross weight of four and one-half tons and an enclosed cabin for eight passengers. At that time the plane was much larger than any other in existence and was usually considered as too heavy to be able to fly or at least to be practical. The *S*-21 was completed and during the spring and summer of 1913 made many successful flights, demonstrating for the first time the advantages of the large size and multiple power plant. In February of the following year, the *S*-22, another four-engined airplane with a gross weight of five tons, took off with 15 passengers on board, establishing a world record which remained unsurpassed for several years. Since then these figures have been exceeded considerably and at the present time there are several successful airplanes from five to ten times larger and heavier than the modest machines that were mentioned. A Sikorsky *S*-42 transoceanic flying clipper ship, powered by four 750-horsepower engines, is shown at the head of this article. Further to this, a brief study may be made with reference to the largest possible size and weight of future aircraft.

Not long ago there was a great difference of opinion on this subject and many well-informed observers in aeronautics, as well as in the field of science in general, expressed the opinion that with the increase in size, airplanes would lose load-carrying efficiency and finally would even be unable to fly. It was mentioned that nature could produce birds of only a limited weight and when the ostrich exceeded a certain weight it proved too heavy to fly. While this illustrates the case, a scientific and at first glance indisputable explanation was furnished by the so-called law of squares and cubes, which means that when an object is proportionately enlarged the surface will increase as the square, while the volume and therefore the weight will increase as the cube of linear dimensions. This would mean that the structural weight would increase more rapidly than the ability of the aircraft to carry load because the latter depends on the wing area. The limitations in possible size estimated on the basis of this rule, however, were exceeded time and time again and the larger airplanes, contrary to predictions, proved to be the more efficient ones.

The general situation in this respect can be briefly explained as follows. The law of squares and cubes would really condemn a heavy airplane if the latter were to represent a true enlarged copy of a small machine, which as a general rule would be the wrong way to design it. If, however, the plane is correctly studied and the advantages of the large size are properly utilized, greater transport efficiency may be obtained in the larger plane. In simple language, this means that if ten tons of payload were to be transported 3,000 miles, one single airplane would do it faster with the same amount of fuel or would require less fuel for the same speed than would ten smaller planes carrying one ton each.

Space does not permit a study of this question with more details, but in general the opinion of the author is that the limit in the size of aircraft in the future will be dictated not by engineering possibilities, but by economic factors and traffic requirements. Travel by air is essentially a fast method of communication which requires frequent departures in order to be really useful. It is not unreasonable for a passenger or a letter to wait three days

Sikorsky "Ilia Mouremetz" airplane in February 1914; this multiengined craft weighed five tons and carried 15 passengers

Artist's conception of a future transoceanic flying boat

for the departure of a steamer which then would take about one week to cross the Atlantic. If a passenger or a letter were to wait for three days and then cross the ocean in 18 hours in a plane, the long waiting would defeat or at least considerably reduce the value of air service. To make the latter efficient and valuable, daily departures across the oceans and still more frequent schedules across the continent are necessary.

Another factor that will influence the size of the aircraft is the extreme operating efficiency of the airplane for carrying passengers. If, for instance, we compare a transoceanic steamer carrying 2,500 passengers with airliners carrying 100, we may at first think that 25 planes are needed to do the service of one steamer. Actually, however, the steamer will make one trip during a week, while the planes would make at least five trips each; therefore, five airliners carrying only 100 passengers each could replace a large steamer. It appears then that the speed and efficiency of the airliner as a passenger carrier would place a practical limitation on the size long before the engineering possibilities would be exhausted.

This being the case, it does not seem necessary to renew the old argument about the technical limitations of the size of the aircraft of the future. That flying boats of 500 or even 1,000 tons carrying several thousand passengers, could be successfully designed and built is the personal belief of the author; however, for the reasons just discussed, a larger number of ships of from 100 to 250 tons with frequent departures will render better service and will remain the backbone of the intercontinental flying fleet during the next 25 years. The land transports will probably remain substantially below this tonnage because the size of airports, difficulties connected with the use of too big landing gears, and finally general advantages of frequent schedules will place a limitation probably between 50 and 100 tons, on the practical size of land transports for the coming quarter of a century.

The 100-ton transoceanic flying boat is, however, the prospect of the immediate future. Within a few years passengers will travel to Europe on such ships that will cross the Atlantic in less than 20 hours. The flight will be luxurious and pleasant. There will be some 50 comfortable staterooms, a large dining salon that will be used for dancing or games in the evening, promenade decks, smoking lounges, a library, comfortable living quarters for the crew and in general most of the accommodations and luxury items found on board a first-class yacht, except only the swimming pool.

The design of such ships would include many novel engineering problems. The manual power of the pilot would be inadequate to operate the control surfaces of the 10,000-horsepower flying ship. Therefore, the controls would have to be operated mechanically. Powerful engines, as well as numerous auxiliary mechanisms, usually would be located inside the huge wings in special engine rooms under the supervision of mechanics. There would be a supercharging plant, an electric power plant, and a heating plant to maintain comfortable temperatures while the ship is cooled by the 200- to 250-mile-per-hour wind while flying at −60 degrees Fahrenheit in the substratosphere. There would be a long list of other important items and auxiliary mechanisms.

Such problems, however, are now routine engineering work. It will be done in the near future and the new superclipper ships will bring luxury and regularity in transoceanic service. Flights to Europe in from 15 to 18 hours, with Asia or Australia on the second day, and three- or four-day round-trip cruises from New York to the North Pole or to the Amazon River jungles, may be expected to be well in operation before 1950.

Such appears to be the general outlook of some of the aspects of aviation of the near future. The ideas expressed are mostly personal and are believed to be rather on the conservative side. They are based on present scientific information, and on the use of existing power plants and materials as well as on methods of design and construction. A new discovery in aeronautical or even in general engineering may involve a substantial revision. For instance, if a method of safe and economical production and handling were developed for the use of liquid hydrogen as a fuel, a great change would result particularly with respect to long-range aircraft. This would make possible the circumnavigation of the earth along the equator in a nonstop flight without refueling. It would also enable an increase in the performance of nearly every type of aircraft. Other discoveries of similar or of different and possibly unexpected nature may indeed change substantially the outlook that was presented. However, even if it remains within the "program minimum" that was outlined, the immediate future of flying presents a bright and interesting picture and shows that aviation is quickly becoming a major and influential factor of progress.

New 98-Inch Continuous-Strip Steel Mill Opened at Cleveland

IN THE competitive struggle of steel manufacture, the modern tendency is toward the adoption of bigger, faster, and more efficient machinery. In point of size, a new 98-inch strip mill recently placed in service by the Republic Steel Corporation at Cleveland, Ohio, now dominates the field. Recent improvements in lubrication, hydraulics, welding, design of bearings, and electrical control have been embodied in the design of the new mill to make possible the production of extra-wide sheet steel at an exceptionally high speed. Maximum delivery speed of the hot mill is 2,121 feet per minute. It can roll all finished widths from 30 to 94 inches and all finished thicknesses from 18-gauge strip to one-half-inch plate. The plant has a rated capacity of 70,000 gross tons per month.

The mill is located on a 182-acre site six miles from the mouth of the Cuyahoga River. For a distance of almost half a mile at this point the river itself was moved to make way for the mill, more than 1,000,000 cubic yards of earth being moved in excavating for the new river channel and in filling the old river bed and a nearby swamp. More than 19,000 concrete piles averaging 40 feet in length were driven into the new fill and 120,000 cubic yards of concrete were poured to provide a foundation for the superstructure and the heavy mill equipment.

The total electric power demand of the entire mill is 20,000 kva. Three-phase 60-cycle electric power supplied by the local utility company is conducted directly to the strip mill motor rooms through an underground duct system at 11,000 volts. Both alternating and direct current, at voltages of 2,300, 600, 440, and 250, are required by the mill's electrical equipment. For the hot-mill finishing stands and the cold-reduction-mill stands, direct current is supplied at 600 volts by four 6,000-kw motor generator sets. For the roughing-mill main-drive motors, general-service water pumps, spray pumps, and air compressors, energy is supplied at 2,300 volts from a 12,000-kva transformer bank. The 250-volt d-c supply is obtained from three 1,500-kw motor generators driven from the 11,000-volt service. For lighting and auxiliary motors throughout the plant, a 3,000-kva transformer bank reduces the voltage to 440. To save on length and cost of interconnections between these transformers, switchgear, and motors, the transformers are of the non-inflammable, nonexplosive type and are located in the motor room proper.

The hot mill requires almost 40,000 horsepower for main-drive motors alone. The roughing-mill main-drive motors are 3,000-horsepower, a-c wound-rotor motors controlled by slip regulators. Three of them are provided with heavy flywheels and are automatically controlled to smooth out the peak loads. Main-drive motors of the first five finishing stands are 4,500-horsepower adjustable-speed shunt-wound d-c motors, bus controlled by the Ward Leonard system. The last finishing stand is driven by a 3,500-horsepower motor of the same type.

Altogether the mill contains 1,420 motors with a total rated capacity of 123,000 horsepower; 58 motors are rated at 100 horsepower or more, and of these, 23 are rated at 1,000 horsepower or more.

Republic's new strip mill is said to be the first ever designed with run-out tables and coilers driven by individual d-c motors instead of a-c motors. The operating requirements of these tables are severe, for the rollers must start from rest, accelerate to a high speed, decelerate, stop, and reverse in a very short time. These d-c motors, which are totally enclosed, shunt wound, of the ball-bearing type, are used in sizes of 4.5 horsepower or less on table rollers, and 25 horsepower or less on coiler rollers. The use of d-c motors foregoes the conversion losses of d-c to a-c motor generator sets, simplifies the control apparatus, and saves substation space because control equipment is compact and the number of motor generators is reduced. Only two 1,000-kw motor generator sets are required for the d-c run-out and coiler motors.

The hot-mill motor room, which is 576 feet long by 65 feet wide and houses five of the seven motor generator sets and all the hot-mill main-drive motors, is said to house the largest concentration of electrical rotating machinery (in horsepower per square foot) of any industrial plant ever built. All equipment is operated from one control desk in the motor room.

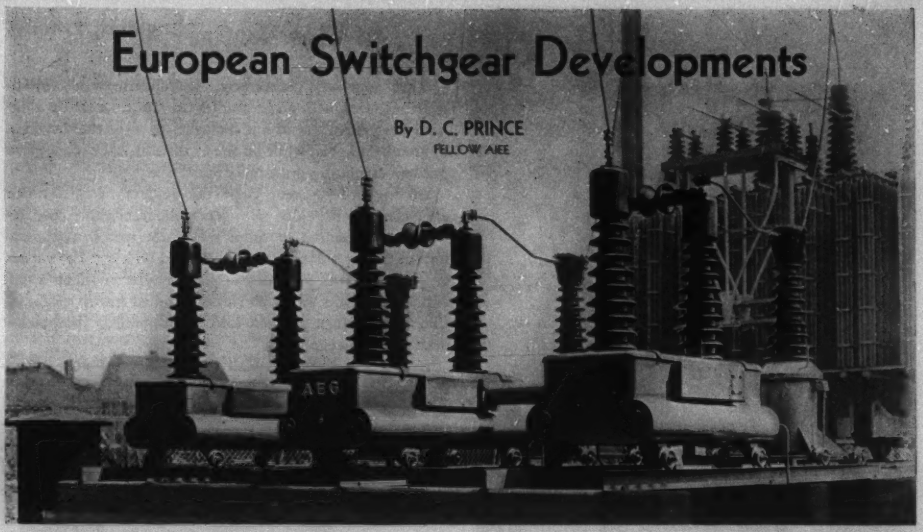
The oil circuit breakers connected to the 11,000- and 2,300-volt equipment are enclosed in metal-clad units located on the main floor of the motor room. Wherever possible, cable was placed in conduit and imbedded in concrete and, excepting overhead power feeders for general service, is lead covered.

Illumination is supplied by about half incandescent lamps and half high-intensity mercury-vapor units, which are alternated throughout the mill. A minimum intensity of 7 foot-candles has been provided, with 15 foot-candles being used generally throughout the mill. For the mill buildings proper the lighting load is approximately 900 kw.

The runout-table rollers of Republic's 98-inch strip mill are driven by 278 d-c motors

European Switchgear Developments

By D. C. PRINCE
FELLOW AIEE



AN electrical engineer visiting Europe is immediately struck by the wide differences in design of switchgear compared to familiar practices in the United States. In England, metal-clad gear is nearly universal except for the highest voltages and even at 132 kv there are metal-clad gears. On the Continent there are almost no metal-clad gears. This does not result in any similarity between Continental stations and American open switching stations with their rows of tank-type circuit breakers. In France some tank-type oil circuit breakers still are being installed but a variety of different designs are appearing, while in Germany the tank-type circuit breaker may be said to be altogether obsolete.

This transformation has been going ahead with increasing momentum for about ten years. Many causes doubtless contribute to it. The supply of oil alone is a serious factor in countries like Germany and Italy which must import every drop of the precious liquid. Steel also is scarce in these countries and must be conserved where possible. Angry clouds of war never seem to draw below the horizon and extra tank cars of oil at vital distribution centers might furnish unnecessarily vulnerable targets.

These reasons would not apply to the United States perhaps with the same force but there are others. The oil circuit breaker has had a long and honorable service record here. Since the introduction of powerful testing plants, the reliability of operation under fault conditions has been greatly improved. Early foreign designs tested in the United States have appeared less rugged and their behavior has been correspondingly less impressive. The frequency and seriousness of circuit-breaker failures abroad is not known but the situation has been serious enough to excite governmental bodies and fire underwriters in Germany, at any rate.

Three years ago American engineers listened to this story with the attitude, "It can't happen here." Since then three major system shutdowns have occurred, not the result of oil-circuit-breaker failures, but involving soot from oil to greater or less degrees. They have, therefore, reached a crossroad. A check must be made to determine whether their instrumentalities are the best for their conditions or whether they can learn anything to their advantage from European practice.

This problem is much more serious in the United States than in Europe. The very standard of living is based on a measure of uniformity in practices. Americans wear mass-production clothing, eat mass-production food, ride in mass-production automobiles, and sleep under mass-production roofs. They cannot enter lightly upon a program of making every circuit breaker different from every other circuit breaker without a certainty of increasing costs on the already groaning utilities. It is with this in mind that European switchgear developments have been studied to see if a change in course is called for and, if so, whether there is any escape from the condition of chaos which exists there. Views on European circuit breakers seem as varied as views on politics. Calm analysis should be possible in engineering even where it is not possible in the social field.

Written especially for ELECTRICAL ENGINEERING, based on an address presented before the AIEE Philadelphia (Pa.) Section, November 8, 1937.

D. C. PRINCE is chief engineer for the Philadelphia works of the General Electric Company at Philadelphia, Pa. He is a native of Springfield, Ill., and received degrees from the University of Illinois. In 1913 he entered the railway department of the General Electric Company, and the following year joined the staff of the Illinois Public Utility Commission; during 1917–19 he served as a lieutenant in the ordnance corps of the United States Army, then returned to the General Electric Company in the research laboratories at Schenectady, N. Y. In 1931 he was transferred to his present position in Philadelphia. Mr. Prince is a member of the AIEE committees on protective devices and Lamme Medal, and is the author of several papers.

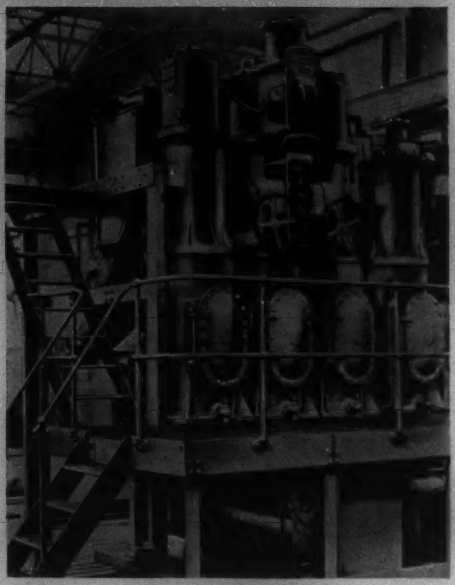


Figure 1. Front view of Metropolitan Vickers metal-clad switchgear, employing single-break circuit breaker—33 and 66 kv

There is a very pronounced difference between switchgear practices in England and on the Continent. In England the general trend has for years been in the direction of metal-clad gear, while on the Continent, both indoor and outdoor structures are largely open.

In England for some years the tendency was to make enclosures continually stronger and larger, and this development resulted in some very large and heavy gears for the higher voltages such as 33 and 66 kv. The earlier gears, in general, were of the plug-in type in which a circuit breaker was either elevated or rolled into position so that its bushings plugged into corresponding receptacles in the bus structure.

In the new gears, especially at the higher voltages, the trend appears to be away from air plug-in gears altogether; and in the direction of a gear in which the disconnecting switches are of a more or less conventional type immersed in oil. The development also includes special circuit breakers designed to be a part of metal-clad gear. One example of this kind is shown in figure 1, which is a Metropolitan Vickers gear built for 33 and 66 kv. The circuit breakers have a single-break explosion chamber enclosed in a metal cylinder. A section of such a gear is shown in figure 2. It has a single break and a Metropolitan Vickers explosion chamber arranged in the center of a vertical steel tube. The ends of this tube are blocked off to separate them from the disconnecting switch compartments. Bushings passing through these barriers carry bushing-type current transformers. The circuit breaker is thus an integral part of the gear. Maintenance is carried on in place by first isolating the circuit breaker through its disconnecting switches, after which the oil is drawn off and the manhole cover removed, giving access to the interior.

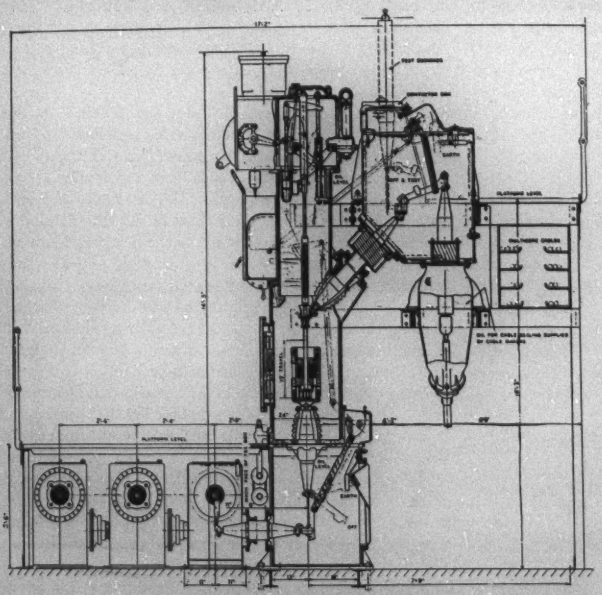


Figure 2. Cross-section drawing of typical Metropolitan Vickers metal-clad gear, single-bus layout

In France, and for that matter everywhere on the Continent, metal-clad gear has made very little progress. The general trend is away from the conventional tank-type breaker as American engineers know it, and a large variety of alternative designs is being tried.

Figure 3 shows a low-oil-content breaker by Als-Thom. A single explosion chamber per phase is depended upon, located in a Herkolite tube, which is in turn surrounded by porcelain weather protection. Access to the contacts is obtained by raising the cover. Drawing off the oil is not necessary, so that inspection and maintenance work can be carried on in a very few minutes with a minimum of difficulty.

and Sweden

Breakers of this type have been made, employing an explosion chamber similar to that developed by Metropolitan Vickers, although more recent designs bear more resemblance to the oil blast with its intermediate floating contact.

In the high-voltage-breaker field, the general arrangement shown in figure 3 is employed by a number of companies, including Delle in France, Brown Boveri in Switzerland, and Siemens in Germany. For lower voltage, the Delle company in France has developed an air-blast breaker shown in figure 4 in which the arc is transferred by the air blast to a circuit containing resistance, the function of which is to reduce the current and bring it nearer to unity power factor for ease of interruption. Als-Thom in France, Brown Boveri in Switzerland, and AEG in Germany all make circuit breakers of the air-blast type, but this resistance feature is peculiar to the Delle design.

Figure 5 shows a Delle breaker in which the pressure is supplied by a piston. The capacity of this design is limited, since only a moderate amount of air can be supplied by a reasonably powered mechanism.

Figure 6 shows a low-oil-volume breaker recently announced in Sweden. It is interesting to note that whereas the Siemens company advocate the "expansion" theory of operation, the Swedish company has chosen to attribute the operation of its device to "contraction." Just how this difference is interpreted in physical structure is not known to the author.

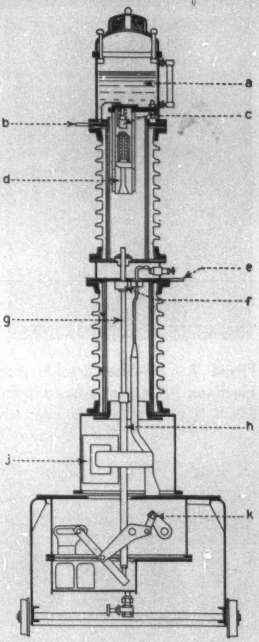


Figure 3. Low-oil-volume circuit breaker (Als-Thom). An oil blast explosion chamber is mounted in a fibrous insulating tube, which is in turn enclosed by a porcelain weather - protection shell. Design provides a single break in oil

(a) Expansion chamber
(b) Upper (outgoing) terminal
(c) Upper fixed contact
(d) Extinguishing chamber
(e) Lower (incoming) terminal
(f) Lower fixed contact
(g) Moving contact
(h) Insulating rod
(j) Current transformer
(k) Mechanism

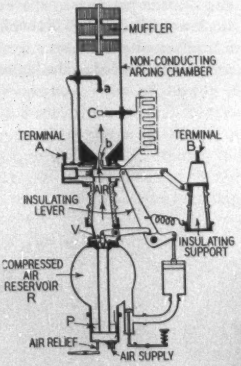


Figure 4 (left). Air blast circuit breaker (Delle). Air blast transfers the arc from the main contacts to auxiliary contacts in series with a resistance

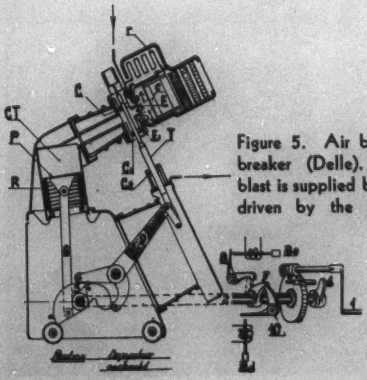


Figure 5. Air blast circuit breaker (Delle). The air blast is supplied by a piston driven by the mechanism

Figure 6. Low-oil-volume 220-kv oil circuit breaker, made in Sweden by Allmana Svenska Electric Company. A blast of oil is produced by a differential piston driven by arc pressure. Manufacturers have chosen to call it a "contraction" breaker in contradistinction to the "expansion" breaker made by another Continental firm

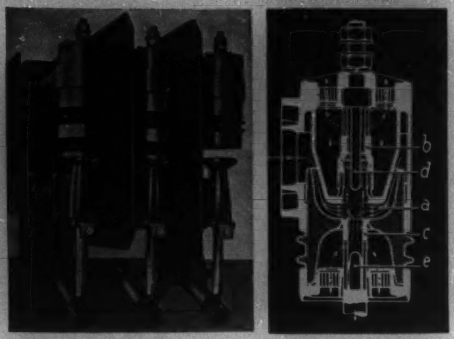


Figure 7. Air-blast breaker manufactured by Voigt and Haeffner. Air is introduced in the middle of the arc stream, which is then blasted in both directions as shown by the arrows

Figure 7 shows an air-blast breaker manufactured by Voigt and Haeffner. The distinguishing mark of this design is that air enters midway of the arc and blows against both electrodes, as compared with the single direction of motion in the more conventional types of air-blast design. A new AEG design will be shown a little later, in which this procedure is exactly reversed.

The lower-voltage design of expansion breaker developed by Siemens in Germany is shown in figure 8. The three explosion chambers, one per phase, contain a liquid called "Expansene" which has a water base for circuit breakers up to approximately 40 kv. It may be noted that the break is visible in the open position and that there are no surfaces exposed to the interrupting liquid across which the current can creep. A higher voltage and larger capacity design of expansion breaker is provided with a disconnecting blade which operates from the main mechanism and isolates the circuit breaker from the circuit in the open position.

Figure 9 shows a typical section of the expansion design particularly applicable to the higher-voltage ratings. A single-break-per-phase explosion chamber is employed for the lower voltages. This explosion chamber is made up of a number of parts held together by springs, so that the pressure is relieved at the higher currents.

Figure 8. Expansion (water) circuit breaker manufactured by Siemens. Contacts are withdrawn completely from the expansion chamber, providing air insulation in the open position

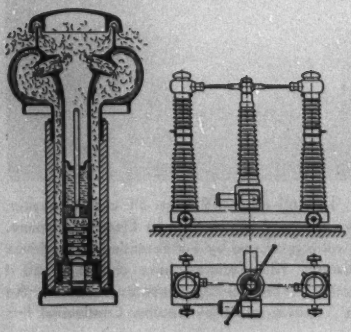
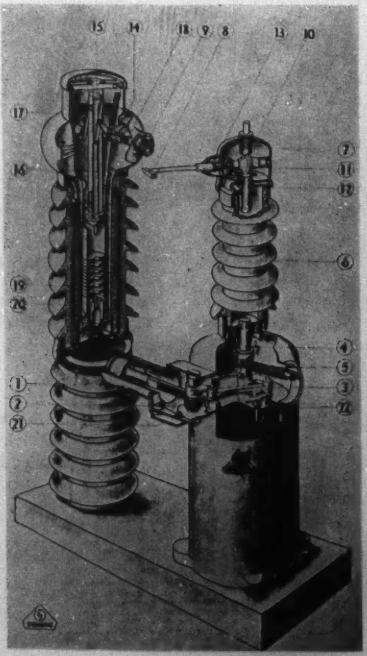


Figure 9. Diagrammatic sections of high-voltage expansion breaker manufactured by Siemens. Rotation of one column first withdraws the contact from the expansion chamber; further rotation withdraws the disconnecting blade, providing air for ultimate insulation



For voltages higher than 40 kv the liquid used has an oil base instead of the water base; and for the highest voltages, two explosion-chamber units are arranged in series. The high-voltage arrangement is shown in figure 10. The upper section of each end column contains an explosion chamber. The rotating central column, besides providing a disconnecting function, is used to operate the explosion chamber contacts. A disconnecting blade engages a jaw coupling, and then rotates so as to operate the vertical contact in the explosion chamber.

AEG has advocated the use of a single air-blast type of circuit breaker throughout the entire voltage and capacity range. However, where small breakers are installed singly, it has been found that the necessary air supply constitutes an undue handicap, and the chemical resin breaker, figure 11, has therefore been brought out to fill this field. The structures resembling explosion chambers contain tubes of urea resin, which when exposed to the arc give off quantities of gas by which the arc is extinguished. AEG has also produced water breakers of the type shown in figure 12. An explosion chamber containing water is located in the center of each pole. Circuit breakers of this design are not now in production although some have been made in the past and are in successful operation.

The principal output of AEG is in air-blast circuit breakers of the type shown in figure 13. The construction of these is shown more in detail in figure 14*a*. Air is supplied through an electrically operated valve at the top of the air tank, both to close and open the breaker. For the closing operation, the air passes through the small pipe at the lower side of the operating piston. In opening, air passes through the large pipe at the upper side of the operating piston and also to the annular space surrounding the sliding contact *f*. As the contact pulls down, air rushes between the moving contact *f* and the stationary contact *h*, extinguishing the arc. The structure above the contact *h* is a muffler.

A more recent modification of this general design form is shown in figure 15. Here the circuit breaker is made somewhat more compact by relocating the tank, as shown. In these circuit breakers the main air valve for the arc-extinguishing air is controlled mechanically by a cam on the shaft, which operates the contacts. A sectional view of this breaker is shown in figure 14*b*.

Figure 16 is a typical outdoor design of the air-blast AEG breaker. The operating parts are similar to those shown previously, except that larger stroke is provided and that the porcelain weather shell surrounds the Herkolite tube.

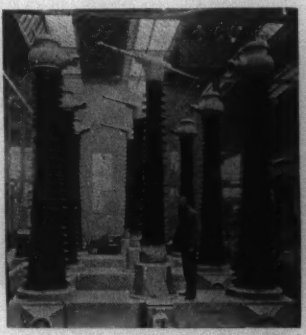


Figure 10. Expansion breaker for 200 kv manufactured by Siemens, embodying two interrupting chambers mounted on current transformers. Operation and isolation are obtained by rotation of the central column

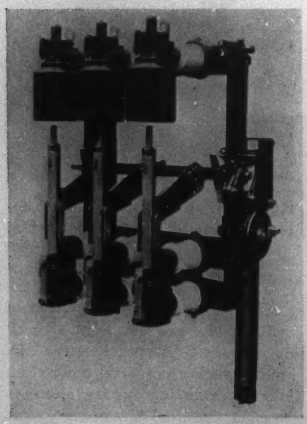


Figure 11. Compressorless gas-blast breaker manufactured by AEG. Contacts are separated within a tube of special resin; arcing evolves gas which interrupts the circuit

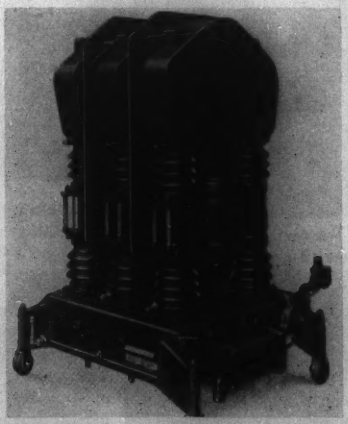


Figure 12. Water circuit breaker manufactured by AEG. This design is said to have given satisfactory service for many years although it now has been withdrawn in favor of gas-blast designs

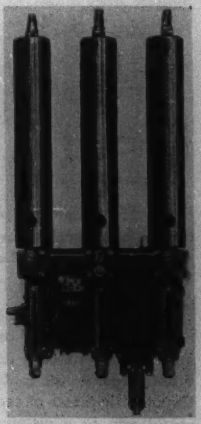
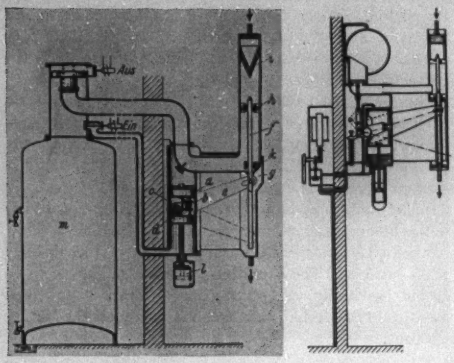


Figure 13. Low-capacity air-blast breaker (AEG). The largest number of air-blast breakers in service are of this type



(a) (b)

Figure 14. Diagrammatic sections of air-blast circuit breakers (AEG)

(a) Method of mounting with mechanism and all live parts on one side of a barrier wall with storage tank and control valves on the other side
(b) Corresponding mechanism and mounting of new design

chanical motion, which then continues, providing ample contact separation when the contacts return to their extruded position upon shutting off of the air supply. This exactly reverses the arrangement of the Voigt and Haeffner design of figure 7. This design seems to be a most happy arrangement for an air-blast breaker as the contacts are at all times visible, and inspection and maintenance work can be carried on with a minimum of dismantling. A three-phase unit of this design is shown at the head of this article; station height is established by the transformer in the background. Current transformers are mounted separately.

Brown Boveri of Switzerland has developed a characteristically different form of air-blast circuit breaker, shown in figure 18. Like the AEG design just described, the contacts are separated by air pressure against a piston. However, a separate set of disconnecting contacts is then operated by the same mechanical mechanism. As soon as the opening air pressure is shut off, the arcing contacts return to their original position, but isolation is maintained

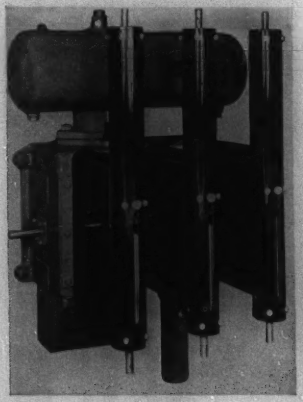


Figure 15. Latest design of indoor-type air-blast circuit breaker. This design is superseding that of figure 13

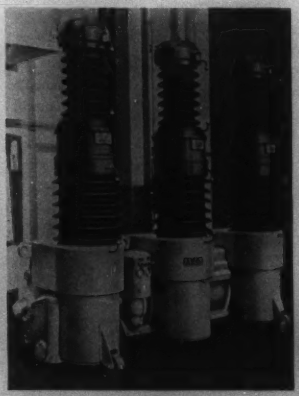


Figure 16. Intermediate-voltage air-blast breaker (AEG), design now obsolete

Figure 17. Single-pole 110-kv air-blast breaker of latest design (AEG)

A recent air-blast design is shown in figure 17. This consists of two vertical columns each carrying a horizontal arm with a contact at its end. The vertical columns rotate to separate the contacts. In opening, air is supplied through the center of each column, out through the horizontal arm to a piston attached to the contact. This piston draws the contact back inside the shield shown, which is made of insulating material. Air then passes out around the contact, through the hole in the shield. The two streams of air meet between the two shields. This operation takes place at the very beginning of me-

by the disconnecting contacts. Another arrangement of this breaker is shown in figure 19.

Higher-voltage Brown Boveri breakers follow the Als-Thom, Delle, and Siemens practice in general, and consist of single-break explosion-chamber interrupting elements incased in porcelain weather shells. Many of the circuit breakers of this general design contain current transformers in their bases. Others have separate current transformers.

Continental practice is quite different from American in that over-current operation is much more prevalent, and

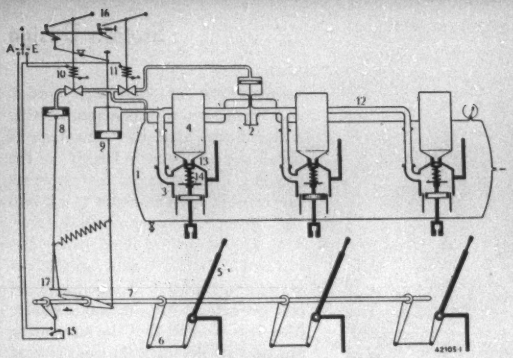
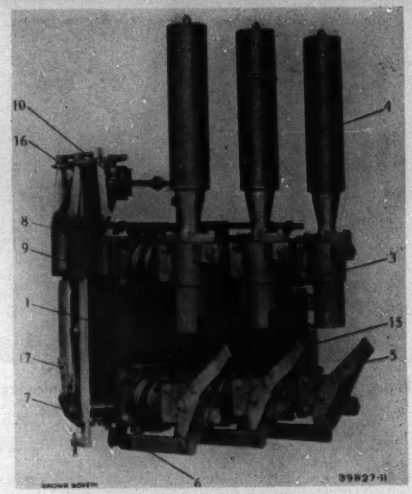


Figure 18. Air-blast circuit breaker manufactured by Brown Boveri (Switzerland)

Interrupting contacts are drawn back by air pressure operating on a piston. Disconnecting blades provide ultimate isolation. Interrupting contacts close by a spring as soon as the air pressure is removed



distance and balanced relaying much less prevalent than in the United States. For that reason the accuracy requirements on the current transformer are much easier to meet, a factor of considerable economic importance where this type of design is involved. Figure 20 shows a three-phase circuit breaker of this type and also a section of the explosion chamber which is reminiscent of the Siemens design.

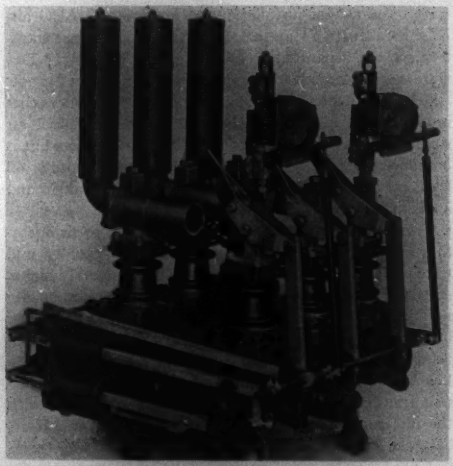
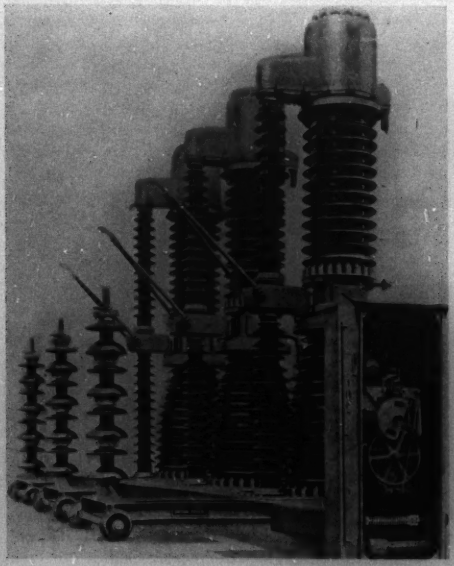


Figure 19. High-voltage air-blast circuit breaker (Brown Boveri)



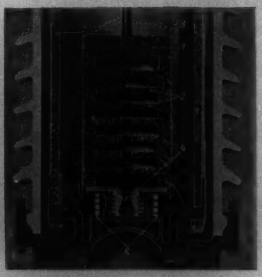


Figure 20. Three-pole low-oil-content high-voltage circuit breaker (Brown Boveri)

Figure 21. A 110-kv outdoor substation, employing newest design AEG air-blast circuit breakers

Circuit breakers of the low-oil-volume designs give stations a radically different appearance from those with which American engineers are familiar. Figure 21 shows one of the newest installations of high-voltage AEG air-blast breakers in a station. In this instance current transformers are separated from the circuit breakers. This station is an example of a practice very common in Europe. All the circuit breakers and all the disconnecting switches are pneumatically operated from the same central air supply. This practice is not limited to air breakers but is found very generally with the low-oil-volume types of oil breakers as well as conventional tank-type breakers and appears to be growing.

There were some instances in England where air operators were provided interchangeably with solenoids; and were preferred because they permitted considerably higher speeds of closing. For comparison with the station design just shown, figure 22 shows the 287-kv oil impulse breakers installed on the transmission line of the Los Angeles Bureau of Water and Power from Boulder Dam to Los Angeles. It may be noted that in this design the current transformers [end columns] are large compared with the interrupting elements of the circuit breaker. Here, balanced current relaying is employed and it was therefore necessary to maintain current-transformer accuracies at high current values, a material economic handicap as compared with Continental design.

Since economics has been mentioned, it may be interesting to compare a few sizes of circuit breakers made in the United States with the nearest comparable designs made abroad. Figure 23 shows such a comparison for a 75,000-kva 15-kv breaker. Manufacturing costs in the United States, England, and France are substantially comparable although European costs are less. The German breaker is not comparable in duty. The German tank-type breakers are produced only for export and are of a very light-duty type. This is apparent in the comparison of "Weight Less Oil" on the same chart. It may be observed that the costs per pound of the German and the American breakers are of the same order.

A breakdown of this manufacturing cost indicates that the advantage of the European is very largely in the matter of labor rates per hour; whereas the number of man-hours going into the breaker is very much greater. Two factors are involved here. Because of the lower hourly rates, labor-saving equipment and processes need not be applied to the same extent. Also, it is possible that the accounting practices are not quite the same so that the man-hours cannot be interpreted literally. At the same time, it is obvious that in the United States it has been necessary to reduce the number of man-hours materially below that of the European competitor in order to secure a comparable cost.

Figure 24 shows a 1,000,000-kva circuit breaker of the tank type. In this size, in spite of the wage differential, it has been possible to show an over-all lower cost for the American breaker as compared with the French and German, although the English product is still lower in cost.

Figure 25 carries the same comparison through to the large 1,500,000-kva circuit breaker. In each of these instances tank-type breakers are being compared. Such tank-type breakers are practically obsolete except in England. It was desirable to compare the relative cost of the low-oil-volume types. Here direct comparisons

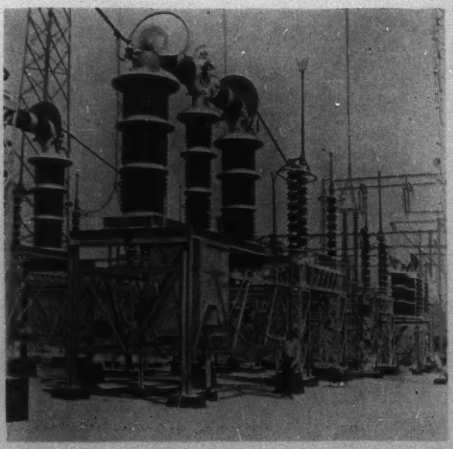


Photo courtesy of D. M. Simmons

Figure 22. A 287-kv switching station, employing low-oil-content impulse breakers, of the Bureau of Water and Power, City of Los Angeles, Calif.

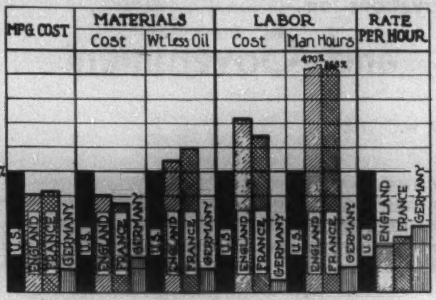


Figure 23. Cost comparison of small circuit breakers

75,000 kva, 15 kv, 600 amperes

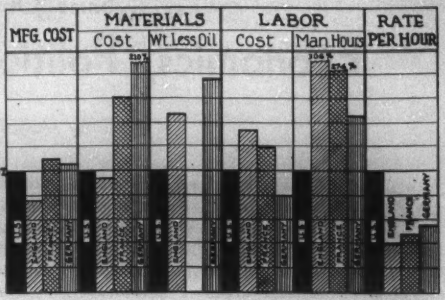


Figure 24. Cost comparison of medium circuit breakers

1,000,000 kva, 15 kv, 1,200 amperes

are difficult because of the extreme differences in the material employed. However, it appears that in general there is a saving in material, in favor of the low-oil-volume type, whereas the man-hours of labor are greater. Thus, such designs would tend to compare unfavorably in the United States where the labor rates are considerably greater. However, it is hoped that ways will be found of equalizing these costs so that the tank and low-oil-volume designs can be compared at some future date on their merits, from a performance standpoint.

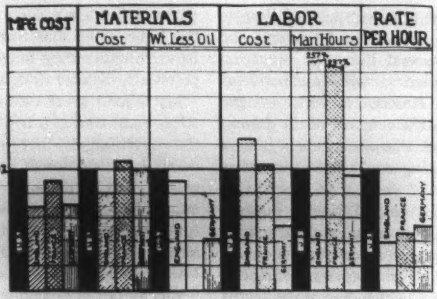


Figure 25. Cost comparison of large circuit breakers

1,500,000 kva, 115 kv, 600 amperes

There is some tendency to regard the lower wage rate paid abroad as a matter of international exchange. We wonder whether, by devaluing the dollar, the United States might be made competitive with these foreign countries. However, it is believed that the difference goes deeper than foreign exchange rates and is really a question of living standards. Figure 26 shows the number of hours which must be put in by a workman to pay for a typical grocery order, consisting of one quart of milk, one loaf of bread, one dozen eggs, and one pound of meat. In every case the European has to work two hours and more for every hour worked by the American laborer to secure the same groceries. These differences are in general greater than the differences in wage rates as shown in circuit-breaker cost comparisons, that is, the foreign worker receives fewer dollars and each dollar buys less.

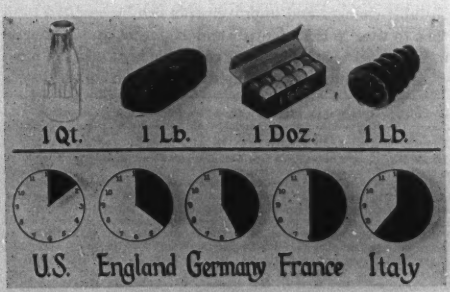


Figure 26. Comparative costs of necessities in hours of labor in the United States and other countries

Wherever the higher purchasing power of the American worker makes it possible to distribute manufactured products in sufficient volume, the costs in the highly mechanized industries are less both in currency and in the equivalent hours of labor than in foreign countries. In apparatus produced in limited amounts, even the highly mechanized factories cannot fully compensate for the higher labor rates, so that some protection for the American workman is necessary. His living standards must be protected from outside competition just as his social standards are protected from undesirable alien influence.

The same objection does not apply to foreign designs. Perhaps Italy cannot afford to store tank cars of precious fuel in circuit breakers. Low oil or oilless designs are certainly safer from air raids. Porcelain may be relatively cheaper than iron in Germany. After these and other factors have been weighed, those elements of European design which compare favorably with American for home operating requirements will be incorporated in domestic practice. The problem is to find which these elements are, and how they can be combined into an acceptable domestic design.

Some Observations on

Economics, Politics, and Government

By JAMES D. MOONEY

On the basis of 20 years' observation of governments in various parts of the world, the author presents here some opinions concerning the functioning of those governments and draws some comparisons between the American form of government and those abroad. He urges all American engineers to contribute intelligent support to their established political system.

MY FIRST trip abroad was with the American Expeditionary Forces as one of the two million men who went over to France to make the world safe for democracy. During the past 20 years, I have spent about half my time abroad. It has been my good fortune to occupy a front seat at many political dramas during those 20 years—the turmoil in Germany, the throwing out of royalty in several European countries, many revolutions in Latin America, and the experiment in so-called communism in Russia. Besides, I have always had a financial stake in the outcome of the drama; such an interest has a way of sharpening one's powers of observation, and of deepening one's sight into what is really going on.

Out of this experience, then, may I simply make a report on my observations of governmental structures abroad. Perhaps, too, I may offer a few suggestions as to how we can do our part in keeping our own American governmental house—the house which has sheltered us comfortably and even luxuriously for 150 years—weather-stripped and insulated against the economic tempests and political hurricanes which beset us at the present time.

In this report and recommendation, I should like to leave with you but four ideas:

1. That the terms fascism, communism, socialism, and democracy are of little value in comparing the forms of government throughout the world.

2. That governments differ principally according to the extent to which they control the lives of their citizens.

3. That the trend of many governments today, *and the trend which constitutes a danger for us in America*, is the trend toward too high a degree of integration—too great a control over every area of the lives of men.

4. Finally, that our most practicable defense in America against too much government in our private economic lives is the maintenance and preservation of our traditional two-party political system, the system that has divided us, at least at election time, into Democrats and Republicans.

Little Significance to Political Terms

While Walter Lipmann, Dorothy Thompson, General Johnson, Heywood Broun, and other columnists have been battling passionately about how many economic angels could stand on the point of some political needle, called communism, fascism, socialism, or democracy, I have been forced into the conclusion by experience that there is very little significance to these terms at all.

My first great disillusionment about these political terms came during my experience when I was contributing my infinitely small bit toward making the world "safe for democracy." In that war I discovered along with many others that symbols didn't make much difference—that underneath their various uniforms men had pretty much the same hopes and fears, joys and sorrows, loves and hates, whether they fought for emperor or czar, king or potentate, dictator or democrat.

My second great disillusionment about these political terms came during a trip through Russia in 1931. I had the opportunity at that time to observe throughout Russia many vast industrial projects under construction—the great hydroelectric power plant at Dnieperstroy, the coal mines of the Donetz Basin, the huge tractor and agricultural implement plants at Karkhov, and the vast state farms in the Caucasus. I had understood meantime that I was going to observe an experiment in Communism.

But all of the economic life in Russia, as I saw it, had the same general pattern I had observed throughout the rest of the world, including my own country. When I confronted various Russian officials with this observation, they explained to me that they hadn't yet had time to get around to Communism, they were too busy with their five-year plan!

Universal Pattern of Economic Life

It has been my general observation that not only in different countries but from generation to generation men go on earning their living in very much the same manner. Notable changes and improvements can be credited from time to time to the scientists and engineers, and in general to improved technology, but economic laws and the processes of production and distribution seem to display a

Essentially full text of an address delivered at the "All Engineers Dinner" held during the Eighteenth Annual Assembly of American Engineering Council, Washington, D. C., January 14, 1938.

JAMES D. MOONEY since 1923 has been vice-president in charge of overseas operations of General Motors Corporation, New York, N. Y., and president of General Motors Export Company. He has received the degree of bachelor of science from New York University, and the degrees of mechanical engineer and doctor of engineering from Case School of Applied Science. He began his career as mining engineer in 1909, later becoming associate editor of the Hill Publishing Company, New York, N. Y. (1911), and sales manager of the Hyatt Roller Bearing Company (1915). During the World War, he served as captain of the 309th Ammunition Regiment, 84th Division, United States Army, in France. In 1920–21 he was president and general manager of the Remy Electric Company. Mr. Mooney first became affiliated with General Motors in 1921, when he was appointed general manager of the General Motors Export Company. He is a member of The American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, and the Society of Automotive Engineers.

lovely contempt throughout history for changes in the political complexion of government.

Farming, spinning cotton, weaving cloth, making shoes, building ships, manufacturing motor cars, operating railroads, department stores, fruit, vegetable, meat, and fish markets, and trading posts, display no more variation in their character in different countries than can be discovered within the boundaries of any one country. In other words, they show no variations whatsoever that can be ascribed to political boundaries. These processes of production and distribution vary only according to the degree to which methods have been improved through the use of tools and technology.

Economic Betterment Used as a Political Slogan

Meanwhile, and particularly since the middle of the nineteenth century when the industrial revolution got into high gear and brought economic issues sharply to the fore in the western world, politicians have pre-empted or achieved authority under one economic plea or another to the masses. America has no monopoly on the "full dinner pail" we inherited from Mark Hanna, the "chicken in every pot" Herbert Hoover insisted we take even if we liked sirloin steak better, or the New Deal that promised us a whole table d'hote dinner but threatens from time to time to leave us grateful if we actually get the hot soup.

These political symbols have been used continually for generations throughout the world, and they are being used universally right now. Symbols for better food, clothing, and shelter are always useful in inspiring either bloody or bloodless revolutions. History shows that empty bellies are the most powerful generators of political change.

I have observed generally in my travels that the pictures the politicians paint that are bulging with full dinner pails for the workmen, and with pots of gold for the business men, have strange or even weird economic colors. In fact, the programs that are projected for taking us all into the land of milk and honey are often quite openly in defiance of some very old and universal economic laws.

Cardinal Principles of Organization

In appraising the many experiments in government throughout the world that have been tried during our generation, it is important that we should not be thrown off the track by the incident that the various revolutionary movements or changes in government have adopted different symbols around which to rally their supporters.

The important point is to recognize the plain fact that once the controlling group gets into power, the practical circumstances of the situation force the new leaders to organize the government according to organization principles that are as old as the hills.

All through the ages, human groups have been organizing themselves to move on various objectives. And in all these organizations, we find three cardinal principles governing their form and operation:

1. Co-ordination, with its implied corollaries, authority and leadership.
2. The scalar process, that is, the delegation of authorities and duties.
3. Functionism, or the division of duties according to the character of the work to be done.

Wherever we find sound group association or group movement progressing effectively toward an objective, we find the formal structure and the process of moving in full harmony with these principles, whether the organization happens to be concerned with government, with industrial problems, with military objectives, or with any other activity in which a group of men work together to get a job done. Further, it is very plain that all effective or efficient governments have functioned according to these principles, wherever the leaders have had the wisdom and the strength to apply them. Still further, we must recognize that the general objectives of government are the same in every country.

Objectives of Government and the Ideal Economic State

The primary objectives of government are first, military, and second, economic in character. National defense, because of disturbed political conditions throughout the world, is today the first consideration; an improved economic order is the second. After national security, people everywhere want more to eat and a greater variety of things to eat. They want more clothes and more shoes. They want more comfortable places in which to live. All governments are seriously concerned with policies which will provide group movement toward these ends.

In the ideal economic state, steps would be taken to see that no economic group, in pressing for its own advantage, did anything inimical to the general economic progress of any group or of the nation as a whole. Every economic group would be challenged to play the game fairly with the others.

In this ideal economic state, the consumer's interests would be placed above all else. A consciousness would be maintained of the fact that only a vigorous production or transformation of raw materials into consumer goods and the efficient distribution of these goods can create a high standard of living. It would be realized that what is inimical to the interests of the consumer is ultimately inimical to the interests of industry. Profiteering, charging more for the goods or services than they are worth, would be discouraged. Racketeering, the levying of tolls on industry for no service at all, would be banned.

In the ideal economic state, the government would stick to its natural functions of maintaining order and security at home, and providing a defense against external enemies. By limiting the extension of its functions, and by performing its own normal functions with thrift, it would avoid laying on productive industries the heavy hand of taxation that has been the cause of the traditional clash between government and industry in all history. Unfortunately, we observe today, in all of the great industrial countries, taxes that are starving or crushing or drying up industry; the thread of this color is weaving itself with tragic irony into all the relations of industry and government.

The Great Difference—The Degree of Integration

Now I have no intention of saying that all governments throughout the world are alike; not at all. But I do want to say that the general structural pattern, the organization principles under which they operate, and the general objectives they seek to attain are universally similar, regardless of what the form is called. And, most importantly, the principal difference I have observed during my 20 years of watching and feeling the various governments in many countries actually functioning—the principal difference between these governments—lies in the degree to which they are integrated. By "the degree to which they are integrated" I mean the extent to which control is centered in the government over the many areas of individual, community, and national life.

It has become quite the fashion for every newly established régime or government to promulgate the thesis that it is projecting new principles into its operations, among which the principle of high integration is usually prominently displayed. Actually, a characteristic which appears in almost all ancient forms of governments is the unlimited range of governmental authority and control. How ironic, therefore, that many modern countries which are generally regarded as conducting experiments in government should actually be operating according to the methods of the governments of antiquity!

Probably those who have traveled or worked professionally abroad have observed that the degree of integration depends upon the amount of external military or internal economic pressure that is being imposed upon the nation at the time. Military or economic crises set the stage for moving a country in the direction of extremely high integration.

Students of history have probably observed that throughout the classical revolutions the most important net result was that the degree of integration was changed. The general process that seems to take place in any one country really represents, from time to time, only a change in the degree of integration of the government, in response to real or simulated emergencies.

Most of the principal countries throughout the world have been moving, during the past 20 years, in the direction of high integration. Governments everywhere seem to be taking an increasing interest in and control over the economic life of their respective citizens. Picking examples out of the bag, I might mention Germany, Russia, Italy, England, and the United States as examples of countries that have had strong enough governments during the past several years to impose in varying degrees remarkable and increasing governmental control over industry, agriculture, and the general economic life of their citizens.

The American Two-Party System

Now, all of us want strength in our government, but at the same time we are eager to retain the greatest possible degree of individual freedom. I am convinced, meantime, that the defense we need in the United States against too much governmental control is to be found in the traditional American two-party system. Our political scheme—our two parties, the Democrats and the Republicans—have given us, at least during the past 50 years, a reasonably good compromise between a strong government and individual freedom.

I should hate to say that they could not have done a lot better. As a matter of fact, I have spent a lot of time and energy during my life, just like any other American, grousing about the government. But I must remind you that men are not angels, and that governments are controlled and operated by men—by politicians. I came to the conclusion a long time ago that it is just as difficult to be a great statesman as it is to be a great financier or a great engineer. My hat is off to the politician who makes a reasonably good average record in the compromise between so-called "sound principles" on the one hand, and, on the other, what people in their inertia will accept at the moment.

To be practical, therefore, we must compare our political and governmental scheme not with some imagined ideal, but with the actual governmental schemes in other countries. Governments abroad seem to go to one extreme or the other: Either the government is so highly integrated, so strong, so "full of itself" that the individual loses too great a measure of his individual freedom, or the government is so weak that it cannot discharge effectively its ordinary functions.

For 150 years our American two-party system has given us a good practicable compromise in government. We have had strong government, but we have escaped extreme tyranny.

"Too Democratic"—A Sign of Weakness

I have emphasized the two-party system rather than identify our American scheme simply as democratic, because there is such a thing possible as a country being too democratic. We shall be very unhappy here if we move into a political situation in which we have several political parties pushing us all around and striving for control. The trouble with having too many parties in the scheme of things is that no one party has enough power to organize a sufficiently strong government when it is elected to office.

We have observed an excellent example of this in France during the past 12 years. You are all familiar with political conditions there, and you know that they have gone from one crisis to another, arising out of their rather disintegrated political situation. France has undergone the formation of several parties, the continual throwing out of one crowd after another, and, generally, a rather chaotic condition.

Likewise, one of the outstanding characteristics of Germany during its weak and transient régime as a republic, was the multiplicity of parties, which kept breaking up and multiplying until the final debacle. An "overdose" of democracy made the patient very ill, and Doctor Hitler was called in. When this sort of thing happens in a democracy, it provides gratifying material for the "integration-

ists" because they like to point to such a collapse as an example of the breakdown of democracy.

The Middle Road—Our Two-Party System

A system like our own, with its two major parties, avoids this disintegrating tendency and gives ample assurance that either party, if elected to office, will be able to carry out effectively the functions of government. On the other hand, the danger inherent in one dominating party unchecked by sound opposition is obvious. The controlling party can swing to wide extremes of national policy without any check or counterbalancing force to bring the pendulum back to center. With the two-party system, however, the party of opposition is always able to act as a check, a strong and effective balance, against any form of extremism in government.

The two-party system, therefore, is in itself our soundest defense against the excessive governmental control inherent in a single, overdominant party. In the other direction it is again our soundest defense against the weakness and disintegration that arise out of having too many political parties.

By now, however, you are probably saying to yourself: "Well, what has all this got to do with me? What can I do about it?" In coming now to my conclusion, I should like to make a suggestion for the answer to this question; the suggestion is this:

I think you and I ought to be either good Democrats or good Republicans.

If we have ideas and opinions on political economy, if we have ideas on how to organize and run the country, if we have ideals for an American government that would be strong and just and fair, we ought to work within the framework of the party that seems, according to our individual lights, to be moving most surely in the direction of those ideals.

How Much Integration, How Much Government Control?

It seems quite obvious that from time to time we shall have external military and perhaps even further internal economic crises which will provide the emotional background for certain kinds of controls that will be imposed upon us by a strong government. I am not saying that I like the prospect of this, I am simply trying to be realistic about the situation and to anticipate what will actually happen.

I believe that the choice which we shall have to make in our political scheme in the impending years is a choice between a highly integrated scheme of government, or a more moderately integrated one. In times of war or in other times of really intense national crises, I think we can all agree that we are willing to submit to a high degree of integration. But, during peace and ordinary times, we want only a moderate degree of integration in our governmental organization.

Accordingly, my suggestion to engineers, who may be worried at the present time about these political and economic problems, is that they identify themselves actively with one party or the other, as dictated by their own interests and convictions. As intelligent, thinking citizens, lend your full support to that party, and in turn expect from that party some reasonable consideration of your point of view for governmental policy.

Certainly, the most practicable thing we can do is to become active in one party or the other. If you don't like the policies of a party in power, then I say, either join that party and help change its policies and leaders, or join the party of opposition and check the politicians in power or throw the rascals out!

Our Individual Liberty

Only in this way can Americans erect a sure and safe defense against too high an integration of our government, against the overreaching governmental control which would deaden our initiative and creative enterprise, crush us with taxes, and rob us of our very liberties themselves.

Finally, we Americans are not ready yet to concede that we must endure in our government a permanently high degree of economic control. We deserve a scheme of government in this country that will maintain for us our traditional individual liberty. We do not want the government or anybody else continually "snapping us into it."

Even if a highly integrated American government could *guarantee* us a higher standing of living, the vast majority of Americans would prefer to risk a somewhat lower standard of living and have a great deal more liberty to live their own private economic lives. There are still millions of Americans, and I am sure engineers belong to this group, who would like to have the privilege at odd moments and when in the mood, of lying lazily under a shade tree and gazing dreamily at the sky.

Electrification of French Railways

ON November 18, 1937, A. Bachellery read a paper before the Institution of Electrical Engineers (London) entitled "Electrification of the Paris-Orleans and Midi Railways." This paper traces the development of electrification on these properties in considerable detail and is regarded as a worthy contribution to the literature available on electrification. This project now involves the following:

Track electrified	5,524 kilometers
Trolley voltage	1,500 volts, d-c
Annual power consumption	470 million kilowatt-hours
Number of substations	111
Installed substation capacity	357,000 kw
Electric locomotives	638
Electric motor cars	152

The paper further points out that electrification has been a profitable investment and that the electrified lines will be extended.

Determination of the Cause of Sheath Corrosion

By W. G. RADLEY

Failure of the lead sheath on underground cable may be caused by stray currents flowing through sections of the sheath or by local electro-chemical action, either of which destroys the lead by corrosion. In order that proper remedies may be applied, the cause first must be determined; some methods are described in this article.

ELECTRICAL development in any country brings with it problems arising from the coexistence of of power and communication networks in close proximity to one another. In Europe these problems led to the formation in 1927 of an international mixed commission as an adjunct to the already existing international advisory committee on long-distance telephony. The primary object of this commission was the joint experimental study by power and communication engineers of problems arising by reason of electric or magnetic induction. Later the scope of the commission was enlarged to cover experiments relating to the protection of buried pipe and cable systems against chemical corrosion and electrolytic damage, and its membership extended to include technical experts representing the gas and water services.

There are, in addition, several national and local committees comprising representatives of all interests, whose function it is to co-ordinate remedial measures against underground corrosion. Before such measures can be planned, it is essential that the cause and mode of failures should be accurately known. There is, therefore, little wonder at the attention that has been given, to measurements designed to study the path of the damaging stray currents.

What follows is confined to one aspect only of the problem, that of the failure of lead-sheathed cables enclosed in buried conduits. It is an aspect that possesses peculiar difficulties of its own when electrical measurements are involved.

Causes of Corrosion

The lead-sheathed cables that are discussed here are drawn into conduits, usually earthenware ducts, and normally have no other protection. This method of construction is usual for telephone cables in Great Britain. The ducts are made as water-tight as possible, but in practice mud and water may find their way inside and constitute a path by which stray currents can pass between the cable sheath and earth. Whenever a direct current follows such a path, metal is removed at points where the current leaves the sheath. In terms of the electrolysis cell, the areas where this takes place are anodic, the corresponding cathodic areas being at points where the leakage current comes on to the pipe or cable system.

However, the water in the conduit may be of a corrosive nature and itself cause direct chemical attack of the lead. In reality, even such corrosion is of an electrochemical nature, but for convenience such cases where the anodic and cathodic areas are very close together and the electromotive force is self-generated will be referred to as direct chemical attack.

Chemical Investigation in the Laboratory

A most important indication as to the cause of the damage comes from the examination of the corroded sheathing and samples of water and other material sent from the field to the laboratory.

Figure 1. Electrolytic corrosion in natural earth water at 0.25 volt (× 23)

After extraneous dirt has been cleaned as far as possible from the sheath, visual examination gives the first indication of the probable cause of damage. Where failure has been brought about by electrolytic action of stray currents, the corrosion usually takes the form of steep-sided pits distributed at random or sometimes in straight lines over the surface of the metal. Without electrolytic stimulation the corrosion tends to be uniform over the surface of the metal and if it causes pits they are shallow and saucerlike.

The corrosion product, to which reference will be made later, having been carefully removed, the pits may next be examined under a low-power microscope in the laboratory. Where there has been electrolytic action, attack on the face of the crystal grains is preceded by corrosion along the grain boundaries. Often it has been found that the

Essentially full text of an address presented before the AIEE Washington Section, November 16, 1937; a similar address was presented at the Fourth Soil Corrosion Conference of the National Bureau of Standards, Washington, D. C., November 15–17, 1937.

W. G. RADLEY, Ph.D. (Eng.), is assistant staff engineer at the Post Office Research Station, London, England, and is responsible for research in chemistry, physics, and protection as well as in certain aspects of telephone engineering. He is member of the sections of the European International Advisory Committee in long distance telephony dealing with telephone interference and the protection of buried cables against corrosion. A graduate of the University of London, he is a member of the Institution of Electrical Engineers.

kind of intercrystalline attack shown by figure 1 had proceeded to such an extent that it was possible to remove individual crystal grains from the sheath with a needle. On the contrary, direct chemical corrosion without external electrolytic stimulation produces a more uniform type of attack in which the crystal boundaries are not subject to preferential damage, as is shown in figure 2.

Other causes such as vibration give rise to intercrystalline disintegration of lead, but when associated with

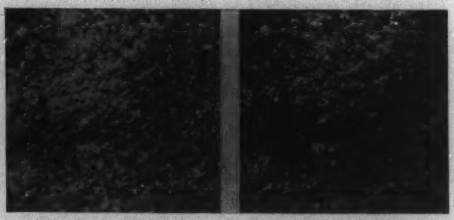


Figure 2. Chemical corrosion in same water as figure 1 (× 23)

certain corrosion products, such disintegration almost invariably points to electrolytic action.

The corrosion products are found in the pits where these are present and fortunately—because these products constitute valuable evidence—they remain intact when the cable is withdrawn from the conduit. After removal from the cable sheath, the corrosion products are analyzed in as detailed a manner as the bulk of the sample permits. To a certain extent their composition varies with that of the water in the conduit. All the evidence, however, shows that lead chloride is the first product of electrolysis in normal English soil waters, but that, in contact with such waters, corrosion products rich to this extent in chlorine are not stable. Notwithstanding this, it can generally be said that compounds containing over about five per cent of chlorine are indicative of recently occurring electrolysis. It is of interest that much carefully checked work in research laboratories of the British Post Office has shown that a corrosion product having a composition corresponding to the mineral phosgenite (that is, the chlorocarbonate) is frequently found after electrolysis has taken place at low current densities. Crystals removed from corroded cable sheathing, but having every appearance of the mineral, have been observed under the microscope and X-ray diffraction patterns have shown that the crystal structure of the corrosion product was the same as that of the mineral. Figure 3 shows typical diffraction patterns of lead salts.

The formation of lead peroxide at fairly high current densities is generally accepted as evidence of electrolysis, and is to a great extent independent of the composition of the surrounding water. The test is easy and distinctive, a little of the material scraped from the sheath being placed in a white dish and moistened with a few drops of Trillat's reagent. If peroxide is present a deep blue coloration appears.

Waters containing normal proportions of chlorides, sulfates, etc., are not usually harmful. The presence of nitrates and nitrites, and of organic matter, particularly in a colloidal form, suggests to the chemist the likelihood of direct chemical attack. Waters containing sewage are particularly dangerous.

Field Surveys

From the examination of the cable and soil water which has just been described, the chemist often will be able to advance a fairly definite opinion as to whether or not damage has resulted from the action of stray currents. The investigation may end here, but some cases of failure reported as due to electrolysis may lead to a detailed electrical survey of the buried cable network with a view to establishing the path and source of the leakage currents and eventually to instituting remedial measures.

As previously indicated, electrolytic corrosion is caused entirely by current passing from the metal sheath to earth by an ionic path, the metal being removed in accordance with Faraday's laws. The essential measurement, therefore, is that of the intensity of the current discharge. When cables and pipes are buried directly in the ground the problem is comparatively simple, and the McCollum earth-current meter developed in the National Bureau of Standards has a wide field of useful application.

Schlumberger's differential method has recently been developed by Gibrat in France and is attracting considerable attention. Three electrodes are placed on the surface of the ground at points equally spaced in a straight line. The central electrode is connected through a galvanome-

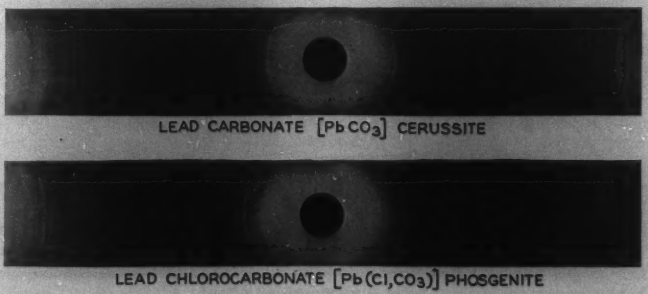


Figure 3. X-ray diffraction patterns produced by lead salts similar to those resulting from corrosion

ter to the junction point of two resistances which form a bridge between the two outer electrodes. An adjustment enables the resistance between this junction point and earth to be made equal by way of either outer electrode. When this has been done it is clear that the junction point between the two resistances is at a potential midway between that of the soil under the two outer electrodes. If the current flow in the ground under the three electrodes is uniform and the soil homogeneous there will then be no potential difference across the galvanometer,

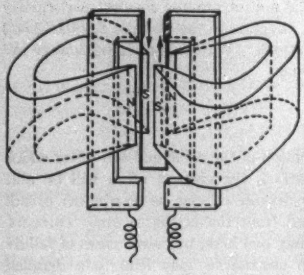


Figure 4. Loop galvanometer, showing the arrangement of the magnets and the loop in its stable hanging position

but, when the electrodes are so placed that a source of current discharge is underneath them a voltage will be indicated. Mathematical expressions exist, by means of which the radial current flow from a buried pipe at a known depth may be calculated when the resistivity of the ground is known. In practice the greatest difficulties are likely to be experienced when making contact between the electrodes and the ground.

The methods just described fail when cables are enclosed in conduits, and it has been the practice of the British Post Office in such cases to rely on simultaneous measurements of the sheath current at two points a short distance apart. At each point of measurement a pair of wires is connected to the cable sheath and carefully adjusted so that both pairs include lengths of sheath of the same resistance. Resistances in series with the testing connections enable the instruments, which are connected across the cable at the two points of measurement, to be adjusted to the same millivolt sensitivity.

Owing to the rapidly fluctuating nature of the stray currents from street railway and other traction systems, it is essential to use some form of photographic recorder for the simultaneous registration of the current at the two points. Further, as the current which it is desired to measure is comparatively small and the resistance of the cable sheath extremely low, the measuring instrument must be capable of giving a reasonable deflection when 0.01 millivolt is applied to its terminals. Also, as it has to be used in the street, it should be readily set up and not affected by a certain amount of vibration. It has been found that a galvanometer consisting of a loop of extremely thin aluminum foil suspended between the poles of two permanent magnets fulfills these requirements. The loop has a resistance of between five and seven ohms. As it is extremely light, its deflections are aperiodic; and, being sealed in a glass cell, it is not disturbed by drafts or air currents. The two permanent magnets are arranged as shown by figure 4 so that, when current is passed round the loop, both limbs are deflected to the same side. The loop is supported by its own stiffness against movement in a plane at right angles to this. For the purpose of obtaining a continuous record, an image of a small part of the loop may be projected by means of a filament lamp on to a photographic film.

Figure 5 shows the complete equipment developed by the British Post Office for use in detailed field investigations. A double record is taken on a film driven forward at a speed of from one to three inches per minute by a small six-volt motor. This and the projection lamps for the galvanometer are supplied from portable batteries, the whole equipment being easily transported. Typical records are shown in figure 6. The two records give by difference the net current flow to earth between the points of measurement and indicate the extent to which the cable length is endangered. The method is open to the criticism that it measures the average current loss over a fairly long length and gives no indication of "hot spots." Although this is true, it is the only method that will measure even the average loss. It also has the great advantage that records obtained in this way to give very clear indications as to the origin of the sheath current. Stray return current from heavily loaded street railways fluctuates very rapidly. With less heavily loaded lines the changes resulting from the movement of individual cars become apparent as shown

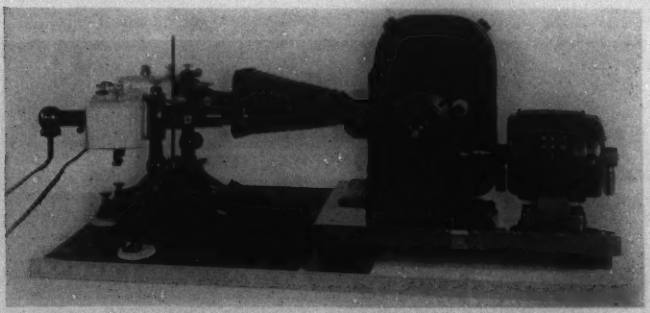


Figure 5. Field equipment consisting of two loop galvanometers and photographic recorder as used by the British Post Office for special investigations

by figure 7. These changes are quite different from the slow variations which alone occur with currents electrochemically self-generated in a long line.

The difficulties in the way of direct measurement of the current discharged from a cable enclosed in a conduit forces one back to measurement of the potential difference causing this current to flow. Unfortunately electrolysis takes place with potential differences no greater than the error involved in measuring them to any simple lead-earth electrode. For this reason some use has been made of nonpolarizable electrodes and calomel half cells, which are not subject to such errors. Figure 8 shows a nonpolarizable electrode suitable for pulling along a conduit in

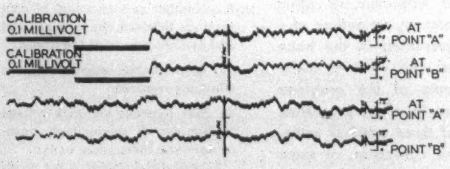


Figure 6. Cable-sheath currents at two points

order to explore the potential field. Connections can be made to the measuring instrument by means of rubber-insulated leads.

In the majority of cases the harmful nature of the soil water is apparent, or the layout of an adjacent street railway gives ample reason for presupposing the occurrence of stray currents. The experience of the British Post Office has led to the conclusion, however, that even then it is necessary to take into consideration the results of all possible tests before forming a conclusion. To the experi-

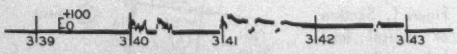


Figure 7. Record obtained by use of loop galvanometer and photographic recorder, showing current in a telephone-cable sheath resulting from movements of a single streetcar

ments which already have been outlined must be added due consideration of the local conditions. In fact, a flair for picking out underlying causes, which is born only of experience, is frequently demanded of those engaged in investigating cable-corrosion problems.

A badly corroded cable removed from an iron conduit is one example of the unusual. Quantities of basic lead carbonate suggested chemical attack; on the contrary, the iron pipe from which the cable was withdrawn was practically dry. The presence of an ice factory and the habitual placing of ice blocks on the pavement above the conduit suggested the real cause, which was the condensation of moisture on the cable. Very pure water, and condensation water in particular, has a serious solvent effect on lead, but is seldom expected in a cable conduit.

Protective Measures

Correct diagnosis is, however, only the preliminary to the proper planning of protective measures. These vary according to the severity of the conditions. In Great

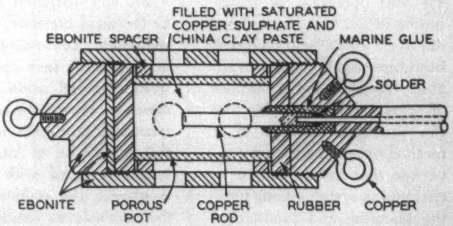


Figure 8. Copper-sulphate nonpolarizable electrode used in cable ducts

Britain the addition of a chemical inhibitor to the grease used for lubricating cables as they are drawn into the conduit has been found to give an increase in life of more than 40 per cent in areas where chemical attack is prevalent. Where the conditions are more severe and result from the presence of stray currents in the ground two modes of protection have been adopted in Europe; cables are either insulated from their surroundings to the maximum extent practicable, or steps are taken to conduct the stray current from the cable sheaths in such a way that no damage is caused.

The first mode makes use of insulating wrappings and special methods of laying, amounting in some instances to the cable being contained in a wooden trough filled solid with a bituminous compound. Such methods naturally result in a cable layout which cannot readily be changed to meet development.

The second mode of protection is applicable to a normal layout consisting of bare lead-sheathed cables drawn into conduit.

As an example of the application of this system, the telephone cable network in Milan has been divided into 16 isolated sections by 343 insulating joints. Each of these sections is connected to the rails of the street-car system at one point by a drainage bond and 354 shunted insulating joints regulate the potential of the cables within the sections.

The conception of such a protective scheme depended on a great number of electrical measurements in the field. That schemes of such magnitude are being applied and that extensive study is being made in many countries of the causes giving rise to cable corrosion are evidences of the problem that has developed underground.

Converting 2.3-Kv Feeders to 4-Kv Operation

Outlining a Successful Method of Procedure

By E. R. COOP
MEMBER AIEE

O. E. SAWYER
ASSOCIATE AIEE

Although the question of the relative merits of converting 2,300-volt distribution feeders to 4,000-volt operation has been treated liberally in technical literature, relatively little has been published concerning efficient methods of accomplishing such conversions once they have been decided upon for economic or other reasons. Hence the accompanying outline of a successful procedure is presented in the hope that it may be of interest and value to many engineers faced with some of the problems involved. The authors are in effect presenting the accumulative results of three years of actual field work incident to the conversion of some 45 distribution feeders.

THE QUESTION of 2,300-volt versus 4,000-volt operation of distribution feeder circuits has been discussed liberally in technical literature that is readily available. Hence it is the purpose of this article to describe the principal features of a method of making such a conversion that has proved to be effectual in systematizing both the planning and conduct of the work involved, presupposing that a decision to do the work already has been made.

An increase in distribution voltage, of course, reduces the voltage drop and line loss for a given load, thereby increasing the feeder capacity. The change from a 2,300-volt ungrounded-delta to a 4,000-volt grounded-wye system accomplishes the desirable voltage increase with a minimum of increased investment, since most of the apparatus used on both systems has the same voltage rating.

Principal features of a change from a 2,300-volt delta to a 4,000-volt wye system are the installation of a fourth or neutral conductor, and the reconnection of single-phase transformers and three-phase transformer banks. Incidentally, the undertaking of such work offers opportunity for the economical accomplishment of general rehabilitation including tree trimming, the installation of tie and sectionalizing switches, and other necessary or desirable system improvements. The great number of details involved in the installation of the neutral conductor and the reconnection of apparatus must be coordinated accurately by a definite system of planning. Co-ordination is especially difficult in this type of work since the project is spread over a large area. In the following discussion, the work is described as nearly as possible in the order in which it was found to be performed to best advantage.

Field Survey

Initially, a thorough field survey is made, recording the following data on a suitable record form.

1. Connections at all junction poles.
2. Size and condition of conductors.
3. Availability and location of pin space for neutral conductor.
4. Number of fuse cut-outs and lightning arresters to be removed and the number to be replaced.
5. Size and location of poles to be replaced, due to deterioration, or in order to provide adequate clearance in the pole top construction.
6. Number and condition of connections between the underground and overhead parts of the feeder.
7. Approximate amount of tree trimming required.
8. Size, location, and high-voltage connections of single-phase transformers and three-phase banks.

Where visual tracing is not possible, in underground construction, for example, a fault locator is used to reveal the connections of conductors. To discover which two of the three high-voltage wires supply a single-phase transformer, the fault-locator signal is impressed on the low-voltage winding (at a customer's service), and the detector is used at the substation or other convenient location. Definite identification of these two wires is made by means of a phase-sequence indicator connected to both conductors and ground.

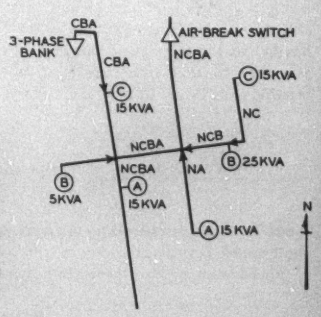


Figure 1. Section of typical final balance plan

Letters indicate phasing at 4,000 volts
Arrows indicate changes in number of wires

This is done conveniently when the transformer fuse cut-outs are opened to allow transferring of one high-voltage lead to the future neutral.

These data ordinarily are sufficient for estimating the cost of the project, and also they serve as the bases for planning the work.

Essential substance of an address presented December 14, 1937, before the Institute's Providence (R. I.) Section. Written especially for ELECTRICAL ENGINEERING.

E. R. COOP and O. E. SAWYER are with The Narragansett Electric Company, Providence, R. I. Mr. Sawyer is currently the secretary of the AIEE Providence Section.

Planning

The first step is to prepare a plan depicting the desired ultimate circuit and equipment arrangement to be attained. This so-called "final balance plan," a typical section of which is shown in figure 1 is a single-line map of the entire feeder indicating the final phase order of conductors and showing to which phase each single-phase transformer is to be connected. The final balance must satisfy two conditions:

1. The load should be approximately balanced along the feeder as well as at the station. Connected transformer capacity usually is a sufficient guide for determining the balance.

2. To minimize possible inductive interference with communication circuits, the three line or "phase" wires should be of as nearly equal length as possible, counting underground cable as the equivalent of 20 times its length in open wire. A total difference of three miles within the area served by any one substation usually is not objectionable.

Having available a record of the existing condition of the system and a plan of the ultimate desired, the problem becomes one of proceeding from the existing to the final state in such a way that no part can be overlooked, and that the plan of work is presented to the field forces in an easily understandable manner. Four sets of plans have been found to accomplish this result, namely:

1. A plan of the neutral conductor that is to be provided.

2. A plan indicating the necessary "phasing" at junction poles.

3. A plan indicating the necessary "phasing" at points where single-phase transformers are installed.

4. Diagrams for reconnecting three-phase transformer banks.

The *neutral plan* is a single-line map of the feeder on which are indicated the sections where the neutral conductor is to be installed, the size and kind of wire to be used, and the position it will occupy on the crossarm. Configuration of the conductors may make more convenient the installation of the new conductor in a position that will enable it to be used ultimately as one of the line or "phase" wires, in exchange for which the existing line wire ultimately would become the neutral conductor. In such instances, the neutral plan is clearly marked, to prevent installation of the new conductor on the white insulator unit customarily used to distinguish the neutral conductor; these white insulators in such sections being placed on the actual ultimate neutral conductor as part of the cut-over process.

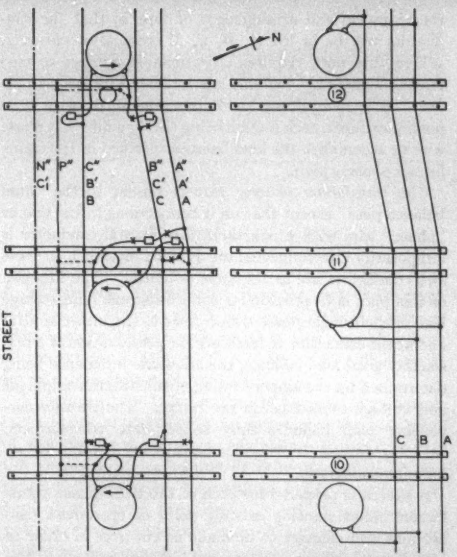


Figure 3. Typical diagram of a three-phase transformer bank, showing existing connections and changes to be made at cut-over in order to secure correct phase sequence and balanced voltage

For legend, see figure 2

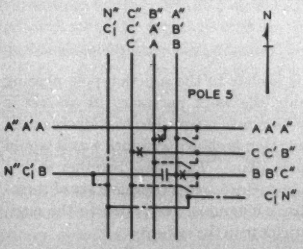


Figure 2. Typical junction pole as shown on the junction pole phasing plan

A B C—Phasing at 2,300 volts before any work is done
A' B' C'—Phasing after preparatory work is done
A"B"C"N"—Phasing at 4,000 volts after cut-over is complete
$A_1'B_1'C_1'$—Phase to which neutral wire is tied at 2,300 volts
—/— Single-pole switch to be closed at cut-over
— · — Connections to be made preparatory to cut-over
—‖— Cuts to be made preparatory to cut-over
- - - - Connections to be made at time of cut-over
—x— Cuts to be made at time of cut-over

It is desirable to standardize on some geographical arrangement of conductors, such as *A*, *B*, *C*, *N*, reading north to south and east to west. The amount of neutral conductor installed depends upon the location and size of three-phase transformer banks and the final balance desired, although in laying out the neutral plan conditions may be encountered that will warrant a modification of the original "final balance plan." Installation data concerning sectionalizing and tie switches are included in the neutral plan along with instructions for making incidental system improvements. The neutral plan covers the installation of all conductors and devices, but does not include the manner of connection which is shown on the junction-pole phasing plan.

The *junction-pole phasing plan* is a diagram showing all conductors involved in the changeover and the location of three-phase transformer banks. A typical junction pole as shown on this plan appears in figure 2. All changes to be made *preceding* cut-over are indicated. These involve tying the neutral wire to a phase wire by means of tempo-

rary jumpers and arrangement of taps so that the conductors will be in the *A*, *B*, *C*, *N* order after cut-over. Where this work requires objectionable outages to customers, temporary switches are indicated for use at cut-over. The neutral conductor is sectionalized with temporary switches, each section being tied to a different phase wire to accomplish the load balance specified in the transformer phasing plan.

The *transformer phasing plan* is similar to the "final balance plan" except that on it connections to the line or "phase" wire with which the future neutral conductor is temporarily interconnected are avoided inasmuch as these two conductors are at the same potential. The function of this plan is to provide for connecting one high-voltage lead of each single-phase transformer to the future neutral and at the same time to facilitate the preservation of a reasonably good load balance, the allowable unbalance being determined by the ampere rating of substation equipment and voltage conditions on the feeder. The transformer-phasing plan includes only single-phase transformers, each three-phase transformer bank being covered by an individual diagram.

A sketch is prepared for each of the three-phase transformer banks showing existing delta or open-delta connections and changes to be made at cut-over in order to secure correct phase sequence and balanced voltage. The diagram also shows the preparatory work required to minimize the outage at cut-over. Figure 3 is a typical diagram of this nature.

It must not be supposed that each of these plans is an unrelated step in the 4,000-volt conversion process and that one may be finished and considered final before all of the others are complete. Actually these several plans are different views of the same problem, and a change in one affects all, just as a change in the plan of a structure affects the elevations. For example: Suppose that a three-phase load on a branch of the main feeder is smaller than the preliminary field survey indicated, or drops off the system entirely. Very likely, the fourth wire would not be added to this branch, thus leaving only two phases available, therefore, for single-phase transformers. In turn, this change in circumstances would require the following chain of modifications: (1) of the "final balance plan," both as to connected load and as to length of line wires; (2) of the transformer phasing plan, (3) of the neutral plan, because no new conductor would be installed; (4) of the junction-pole phasing plan, to show which conductor is to become the neutral; (5) of the transformer bank diagram because, if the load remains, only two tranformers instead of three will be used in the transformer bank to furnish three-phase service. Again, it may be found that connecting a single-phase tap to *A* or *B* phase would block the climbing space on a junction pole that otherwise is in good condition. This would mean that the pole top would require rebuilding, and, if the pole has only a few years remaining life, probably pole replacement would be in order, whereas connection of the tap to the *C* phase would avoid all this extra construction. In such an instance, the final balance, transformer phasing, and junction-pole phasing plans would be involved. As such details continually are arising, a systematic method of notation obviates much confusion.

Figure 5. Voltage- and rotation-testing unit

This is a convenient assembly for checking voltage and rotation of three-phase power services of 575 volts and less. Removable handle for cable reel is shown in place. Cables are distinctively colored near the clips so that connections can be checked from the ground when overhead services are being tested. Below the rotation indicator is an insulating handle to operate disconnects which, when open, leave the voltmeter alone on the test leads. Below the voltmeter is a knob connected to a transfer switch which shifts the voltmeter from phase to phase

Cut-Over

A cut-over plan is similar to the junction-pole phasing plan except that only the work necessary *at cut-over* is indicated. The junction pole referred to previously in the junction-pole phasing plan is shown in figure 4 as it would appear on the cut-over plan. This plan, together with a detailed schedule of procedure, and a complete set of three-phase-transformer-bank diagrams, are issued to the engineers who are to participate in the cut-over.

A day or two previous to the date of change-over, a rehearsal is conducted at which the engineers and their line crews become familiar with the work involved. At this time, red tags are installed on switches that are to be closed at cut-over and white tags are used to indicate cuts that are to be made. The voltage and phase sequence of three-phase banks are checked using the outfit shown in figure 5.

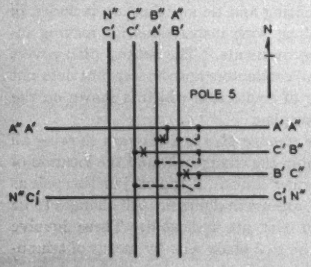


Figure 4. Typical junction pole as shown on cut-over plan

For legend, see figure 2

Elmwood 4-Kv Cut-over—Feeder 7HJ-4

Part III: Headquarters—Pole 52, Reservoir Avenue

1. Disconnect power load—report to headquarters

Sawyer	4 Garden and 13, Beckwith Street	8:05
	Pole 12 and 13½, Pontiac Avenue	8:09
Andrews	Pole 53 and 54, Reservoir Avenue	8:06
	Pole 6 and 6½, Rounds Avenue	8:04
Springer	Pole 08, Wellington Avenue	8:05
	Pole 14, Margaret Street	8:07

2. Stand by for Wilson at:

Sawyer	Pole 4, Pontiac Avenue
Andrews	Pole 20, Rounds Avenue
Springer	Pole 45, Reservoir Avenue

3. Wilson give following instructions and get OK's:

Sawyer	Pole 4, Pontiac Avenue	
	Open three quick breaks	8:14
Andrews	Pole 20, Rounds Avenue	
	Make one cut and one tie	
Springer	Pole 45, Reservoir Avenue	
	Cut neutral jumper	
	Close neutral switch and three quick breaks energizing at 4 kv	8:16

4. Proceed to reconnect power load

Sawyer	Pole 4, Garden and 13, Beckwith Street	8:23
	Pole 12 and 13½, Pontiac Avenue	8:29
Andrews	Pole 53 and 54, Reservoir Avenue	8:36
	Pole 6 and 6½, Rounds Avenue	8:21
	Close neutral switch, pole 23, Narragansett Avenue	
Springer	Pole 08, Wellington Avenue	8:23
	Pole 14, Margaret Street	8:29

5. Proceed to new headquarters—pole 19, Niantic Avenue

Figure 6. Typical cut-over schedule

The cut-over itself usually is scheduled for the early morning hours of an off-peak day, to reduce to a minimum the number of customers affected. Assuming that the preliminary switching, if any, has been completed and checked, the first step is to disconnect the three-phase banks on the first section of the feeder to be changed over. The section is then de-energized, any necessary changes in conductor phase order are made, the neutral is cut clear from its associated phase wire, and the section is energized at 4,000 volts. Reconnection of three-phase transformer banks, and a check of the phase sequence and voltage completes the cut-over of the section. The service interruption seldom exceeds three minutes for single-phase customers or half an hour for customers served by three-phase transformer banks. Figure 6 shows a typical sheet of the cut-over schedule, together with the times at which the various steps were actually performed.

Each engineer in charge of a line crew is responsible for a definite portion of the work, which is co-ordinated by a sponsor engineer, who is in charge of the entire job.

Clean-Up and Final Inspection

Work remaining to complete the conversion of the feeder to 4,000-volt operation consists of the removal of all temporary switches used at cut-over and the balancing of single-phase loads. During the work of balancing the feeder, the neutral lead of each transformer is connected solidly to the neutral conductor and a neutral lightning arrester, consisting of a simple porcelain-enclosed gap, is installed. For the use of the construction crew, a balancing plan is issued which is, briefly, the difference between the transformer phasing plan and the final balance plan.

The final step by the engineering department is a thorough inspection of the entire feeder. At this time all structural details are checked, for example: the removal of temporary switches, the removal of unnecessary lightning arresters and fuse cut-outs, the installation of neutral lightning arresters, and the high-voltage connections of single-phase transformers.

A New Swiss Lake

A NEW LAKE, the Sihlsee, recently was created near Einsiedeln, Switzerland. It forms part of the huge Etzel power project, which the Swiss Federal Railroads have been building in conjunction with the "Nordostschweizerische Kraftwerke," at a cost of 65 million Swiss francs [at par, about $12,545,000].

Back in the year 1797 Goethe, the famous German poet, spoke in one of his Swiss travel memoirs of the possibility of utilizing the waters of the Sihl, which has its origin on the Drusberg in the canton of Schwyz, and which, because of mountainous obstructions, has to describe a left turn shortly after Einsiedeln, instead of being able to proceed directly into the lake of Zurich. Engineering skill now has conquered this obstacle. Near the so-called "Schlagen" a tunnel has been bored through the mountain for high-pressure conduits that bring the heavy volume of water to the power station near Pfäffikon on the lake of Zurich. The new Sihl lake, which incidentally has added greatly to the beauty of the Einsiedeln country, is 892.6 meters [2,930 feet] above sea level; it has a length of eight kilometers [nearly five miles], an average width of 1.4 kilometers [more than three-quarters of a mile], a depth of 20 meters [61 feet], and with an area of 11 square kilometers [four and one-quarter square miles], it assumes 15th rank among Swiss lakes. The Sihl reservoir lake will produce yearly 150 million kilowatt-hours of electric energy—110 million during the winter months.

News

Of Institute and Related Activities

North Eastern District Meeting and Student Branch Convention

A PLEASANT three days are in store for all who will attend the North Eastern District meeting of the AIEE to be held at Lenox, Mass., May 18–20, 1938. Headquarters will be at the Curtis Hotel, and arrangements have been made to house those attending in this hotel and in other hotels in town. Lenox is a beautiful New England village situated about six miles from Pittsfield in the heart of the Berkshire Mountains. Attractive entertainment, interesting trips, and technical sessions have been arranged by the general meeting committee, K. B. McEachron, chairman.

Entertainment

Wednesday evening, May 18, a stag smoker will be held at the Town Hall in Lenox. On Thursday evening a mixed banquet will be held with an interesting speaker. On Friday evening, May 20, arrangements have been made for a student dinner and dance to be held at the Stanley Club in Pittsfield. This is essentially an engineering club whose members are drawn entirely from the employees of the General Electric Company. Every attempt will be made to make the students feel at home, perhaps even to the extent of supplying partners for this dance.

A women's committee, with Mrs. V. E. Goodwin, chairman, is actively engaged arranging entertainment for the women in the form of a card party, drives to several of the nearby colleges, and, if possible, visits to some of the many estates around Lenox.

Technical Sessions

Five technical sessions will be held during the meeting. One of these will be a general session in which there probably will be addresses on science or economics, which subjects are of interest to many members. Other sessions will deal with voltage regulation, industrial applications, and selected topics. Friday morning will be devoted to a student session in which papers will be presented by students from several of the universities and colleges within the District.

Inspection Trips

The Pittsfield works of the General Electric Company, the Crane paper mills, and the woolen industry afford unusual opportunity for interesting and instructive insight into these industries. The schedule for these inspection trips has been arranged as follows:

Thursday afternoon, May 19

1. Pittsfield works manufacturing departments of the General Electric Company (approximately two hours).
2. Plastics division of the General Electric Company (approximately two hours).
3. High-voltage demonstration in the 10,000,000-volt laboratory (three-quarters of an hour).

Trips 1 and 2 are alternates because of time limitations, but those attending either trip will be given the privilege of witnessing the high-voltage demonstration.

Friday afternoon, May 20

A. Arrangements have been made to visit one of the Crane paper mills, where the highest quality linen-bond paper is made by the same company that makes all of the paper for government currency. This trip will include perhaps a half hour in the Crane Museum where an attendant lecturer will explain the history of paper making from beginning to end.

B. As an alternate to trip *A*, there will be an inspection of the manufacture of woolen cloth at either one of two woolen companies in the Pittsfield area.

In addition, trips 1 and 2, listed under Thursday afternoon, will be arranged again on Friday afternoon especially for the students, followed by the high-voltage demonstration. Members who are unable to see all of the General Electric works on Thursday could take the alternate trip 1 or 2 with the students, if desired, in place of trip *A* or *B*.

Rules on Presenting and Discussing Papers

At the technical sessions, papers may be presented in abstract, ten minutes being allowed for each paper unless otherwise arranged or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion.

Curtis Hotel, Lenox, Mass., headquarters for the AIEE North Eastern District meeting

Tentative Technical Program

Daylight Saving Time

Advance copies will be made available as papers are approved, with the exception of the one already published in ELECTRICAL ENGINEERING and for which reference is given. If ordered by mail, price 10¢ per copy; if purchased at Institute headquarters or at the meeting, price 5¢ per copy. The announcement of the meeting to be sent to members within the District and nearby territory will carry an order form for those who wish to order advance copies of papers.

Wednesday, May 18

9:00 a.m.—Registration

10:00 a.m.—Voltage Regulation

*SYSTEM PLANNING AND OPERATION FOR VOLTAGE CONTROL, **T. J. Brosnan**, Buffalo, Niagara, and Eastern Power Corporation.

*VOLTAGE-REGULATING-EQUIPMENT CHARACTERISTICS AS A GUIDE TO APPLICATION, **P. E. Benner** and **G. S. Lunge**, General Electric Company.

*VOLTAGE REGULATION AND CONTROL OF RURAL LINES, **G. H. Landis**, Central Hudson Gas and Electric Corporation.

*THE PERIODIC VOLTAGE SURVEY AS A BASIS FOR DISTRIBUTION DESIGN, **R. W. Burrell**, Consolidated Edison Company of New York, Inc., and **W. E. Appleton**, New York and Queens Electric Light and Power Company.

2:00 p.m.—Industrial Applications

PHOTOELECTRIC WEFT-STRAIGHTENER CONTROL, **C. W. LaPierre**, General Electric Company, and **A. P. Mansfield**, consulting engineer.

REGENERATIVE TENSION CONTROL FOR PAPER WINDERS, **H. W. Rogers**, General Electric Company.

*COMPARISON OF METHODS OF STOPPING SQUIRREL-CAGE INDUCTION MOTORS, **W. I. Bendz**, Westinghouse Electric and Manufacturing Company.

*THE APPLICATION OF CAPACITORS FOR POWER-FACTOR CORRECTION IN INDUSTRIAL PLANTS, **C. E. H. von Sothen**, General Electric Company.

Thursday, May 19

9:30 a.m.—General Session

Probably addresses on scientific or economic subjects of interest to many members.

Friday, May 20

9:30 a.m.—Student Session

2:00 p.m.—Selected Topics

CORONA VOLTAGES OF TYPICAL TRANSFORMER INSULATION, **F. J. Vogel**, Westinghouse Electric and Manufacturing Company.

MULTIPLE LIGHTNING STROKES—II, **K. B. McEachron**, General Electric Company.

PROTECTOR-TUBE APPLICATION AND PERFORMANCE ON 132-KV TRANSMISSION LINES—II, **Philip Sporn** and **I. W. Gross**, American Gas and Electric Service Corporation.

NEW TYPES OF D-C TRANSFORMERS, **C. C. Herskind**, General Electric Company.
EE, November 1937, pages 1372–8

A DIRECT-CURRENT TRANSFORMER, **T. C. Lennox** and **E. V. DeBlieux**, General Electric Company.

*TENSOR ANALYSIS OF ARMATURE WINDINGS—I, **P. L. Alger** and **Gabriel Kron**, General Electric Company.

* These papers are scheduled for presentation but they have not been accepted for publication at the time of going to press.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually five minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser should step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussions to be considered for publication should be typewritten and submitted in triplicate to C. S. Rich, secretary of the technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y., on or before June 3, 1938. Discussion of addresses and papers, which is not for publication, need not be submitted.

HOTELS AND REGISTRATION

Hotel rates during the meeting range from $5.00 to $7.75 per day, American plan, with rates for students as low as $4.50 per day. The Curtis Hotel, meeting headquarters, will handle all rooms whether or not they are in that hotel, and members should make their room reservations by writing directly to the management. Coupon books covering room, meals, entertainment, and trips will be issued at the time of registration at the meeting. A refund schedule has been arranged for those who may wish to omit part of the program.

Advance registration will assist the committees making arrangements and will avoid congestion on arrival. For this purpose an advance registration card will be sent to members in the District and nearby territory. All registrations should be made with L. G. Hamilton, chairman, hotel and registration committee, care of Central Station Department, General Electric Company, 100 Woodlawn Avenue, Pittsfield, Mass. A registration fee of $2 will be charged all nonmembers except Enrolled Students and the immediate families of members.

COMMITTEES

District Meeting Committee: K. B. McEachron, *chairman;* A. C. Stevens, vice-president, AIEE North Eastern District; R. G. Lorraine, secretary-treasurer, AIEE North Eastern District; F. N. Tompkins, chairman, committee on student activities, AIEE North Eastern District; A. Boyajian, R. M. Darrin, E. Huntington, F. R. Longley, H. A. McCrea, Victor Siegfried, and L. Wetherill.

Advisory Board: K. B. McEachron, *chairman;* A. Boyajian, F. F. Brand, V. E. Goodwin, V. M. Montsinger, I. H. Sclater, and E. D. Treanor.

Women's Entertainment: Mrs. V. E. Goodwin, *chairman;* Mrs. M. F. Beavers, Mrs. E. A. Evans, Mrs. G. P. Lehmann, Mrs. J. R. Meador, Mrs. J. L. Thomason, and Mrs. W. L. Young.

Technical Program: A. Boyajian, *chairman;* L. F. Blume, F. M. Clark, F. W. Godsey, Jr., V. M. Montsinger, E. T. Parsons, W. J. Rudge, H. R. West, and F. L. Woods.

Hotels and Registration: L. G. Hamilton, *chairman;* J. R. Barr, B. N. Bowers, R. A. Browne, T. M. Evans, H. S. Hubbard, J. E. Hutcheson, E. K. Kane, and G. P. Lehmann.

Entertainment: W. H. Cooney, *chairman;* M. F. Beavers, C. A. Beers, E. V. DeBlieux, C. W. Germeck, J. R. Meador, and P. N. Osborne.

Transportation and Trips: J. A. Roser, *chairman;* E. A. Elge, S. T. Maunder, A. Palme, C. C. Pilsbury, H. M. Towne, T. R. Walters, and J. H. Watkins.

Student Sessions: F. N. Tompkins, *general chairman;* L. Wetherill, *local chairman;* L. V. Bewley N. M. Case, H. S. Endicott, R. N. Kerchen, W. A. McMorris, and M. E. Scoville.

Publicity: C. A. Read, *chairman;* R. A. Browne, L. H. Burnham, L. W. Foster, W. D. Haylon, C. J. Kettler, and W. L. Lloyd.

Finance: G. W. Wade, *chairman;* J. L. Cantwell, and E. Stanley.

AIEE Section Organized at Muscle Shoals

Pursuant to authorization by the AIEE board of directors, the AIEE Muscle Shoals Section held its organization meeting in the visitors' room of the Wilson Dam power house February 18, 1938. Territory included in the new Section is: Alabama counties—Lauderdale, Limestone, Colbert, Lawrence, Morgan, Franklin, and Marion; Mississippi counties—Tishomingo, Itawamba, Alcorn, Prentiss, Lee; Tennessee counties—Hardin, Wayne, Lawrence, Giles, Lewis, and Maury. This is the Institute's 65th Section.

Officers elected to serve until August 1, 1938, are: B. B. Bessesen (A'17, M'27), superintendent of power, Muscle Shoals, plant, *chairman;* F. E. Bell (M'35), assistant construction engineer at Joe Wheeler Dam, *vice-chairman;* Margaret G. Coyne (A'37), secretary to superintendent of power, Wilson Dam, *secretary-treasurer;* and G. U. Mason (A'24), assistant electrical engineer, Tennessee Valley Authority, Pickwick Dam, B. M. Anthony (A'37), electrical engineer, TVA, Wilson Dam, Ala., R. C. Roberts (A'37), electrical engineer, TVA, Wilson Dam, and J. H. Christensen (A'37), assistant electrical engineer, Wilsom Dam power plant, *directors.*

Summer Convention to Be Held in Washington

The annual summer convention of the AIEE will be held in Washington, D. C., June 20–24, 1938, with headquarters at the Mayflower Hotel. The nation's capital, a center of historical interest and scenic beauty, situated on the banks of the Potomac, provides an ideal setting. Arrangements are being made by the committees for a business program combined with entertainment, trips, and sports, which will make for a pleasurable and profitable week.

In addition to the annual business meeting and the conference of officers, delegates, and members, 1 general session, 11 technical sessions, and 5 conference sessions tentatively have been scheduled. The technical sessions will deal with the subjects of fluorescent lighting, education, electronics, communication, power transmission, protective devices, electrical machinery, instruments and measurements, and selected subjects.

The personnel of the 1938 summer convention committee, appointed by President Harrison, is as follows: General committee—William McClellan, *honorary chairman;* H. W. Osgood, *chairman;* C. A. Robinson, *vice-chairman;* G. L. Weller, *secretary;* A. F. E. Horn, *treasurer;* F. A. Allner, R. C. Bailey, L. D. Bliss, J. V. B. Duer, N. E. Funk, W. B. Kouwenhoven, T. J. MacKavanagh, J. F. Meyer, J. S. Miller, H. S. Osborne, H. M. Southgate, and W. H. Timbie. Chairmen of subcommittees—Roland Whitehurst, *finance;* J. H. Stephens, *transportation;* W. J. Ellenberger, *registration and housing;* H. E. Way, *publicity;* A. O. White, *sports;* R. W. Prince, *inspection trips;* F. M. Defandorf, *technical programs;* S. K. Brown, *entertainment;* and R. C. Marshall, Jr., *women's entertainment.*

© H. H. Rideout

Memorial Bridge which connects Alexandria, Va., with Washington, D.C., scene of the AIEE 1938 summer convention

Report on Telemetering Now Being Revised

To indicate the present status of development of devices used in telemetering and supervisory-control services, a revised report on telemetering, supervisory control, and associated communication circuits now is being prepared by a joint subcommittee of the AIEE composed of members of the committees on instruments and measurements and automatic stations; P. A. Borden (A'13, M'19) development engineer, Bristol Company, Waterbury, Conn., is chairman. The subcommittee's original report on this subject was completed in 1932, and essentially full text of that report (excepting extensive tabulations) was published in the September 1932 issue of ELECTRICAL ENGINEERING, pages 613–20.

Preparatory to revising the report, the subcommittee has sent questionnaires to all suppliers of equipment whose names are known to the subcommittee, and a large proportion of these have been completed and returned for compilation. Any manufacturers or distributors of this class of apparatus who have not yet received or returned questionnaires will assist the subcommittee materially by communicating with H. C. Koenig, chairman of the AIEE instruments and measurements committee, Electrical Testing Laboratories, 80th Street and East End Avenue, New York, N. Y.

New Recommendations for School Lighting Issued

A new booklet "American Recommended Practice of School Lighting," has been issued under joint sponsorship of the Illuminating Engineering Society and the American Institute of Architects and with approval of the American Standards Association. The booklet is the work of a committee that included eye-sight specialists, physicians, research workers, public health officials, architects, and engineers, and their recommendations constitute a comprehensive and thorough study of the subject. These new recommendations supersede those contained in an earlier booklet "Standards of School Lighting" published in 1932.

The primary purpose of this new edition has been to establish criteria of good illumination for the guidance of architects, engineers, school officials, and others interested in the conservation of children's vision and the efficiency of pupils and teachers. Successive sections cover the seeing problems confronting students and teachers; the factors that affect seeing and lighting; the problems involved in natural and artificial lighting of school rooms; how and when natural light may be augmented by artificial light under varying weather conditions; and a discussion of adequate wiring.

Single copies of the new recommendations are priced at 25¢ each, with quantity prices obtainable on request from the Illuminating Engineering Society, 51 Madison Avenue, New York, N. Y., or the American Standards Association, 29 West 39th Street, New York, N. Y.

Handbook of Chemistry and Physics. (2,096 pages, flexible fabrikoid, 4 by 6 1/2 inches, $6.) With some 50 pages of new material and more than 100 pages of previous material revised and brought up to date, the 22d edition of this useful compendium was issued recently by the Chemical Rubber Publishing Company of Cleveland, Ohio. An attempt has been made to include material "on all branches of chemistry and physics and the closely allied sciences that would be likely to find any extended use," although certain types of material of limited and highly specialized use have been excluded, of necessity. A large amount of "accurate, reliable, and up-to-date information," in the ever more closely related fields of chemistry and physics is presented in condensed form. Included are: 4 pages on poison antidotes, treatment for burns, scalds, and fire precautions; 302 pages of mathematical tables; 570 pages on chemical and physical properties and constants; 199 pages of general chemical tables; 195 pages on properties of matter; 156 pages on heat; 20 pages of hygrometric and barometric tables; 4 pages on sound; 108 pages of electricity and magnetism tables; 152 pages of light data; 187 pages of quantities and units; 145 pages of miscellaneous tables; and 30 pages of complete cross index.

Midwest Power Conference. Operated under private direction since 1926, The Midwest Power Conference in the future will be directed through the sponsorship of Armour Institute of Technology, with the co-operation of six state universities and local and national engineering societies, according to the preliminary program of the conference scheduled for April 13–15, 1938. This conference, to be held at the LaSalle Hotel, Chicago, Ill., has been planned to include addresses and conferences covering a wide variety of subjects ranging from the technical to the economic and into the sociological aspects of power progress. Information may be secured from L. E. Grinter, conference director, Armour Institute of Technology, Chicago, Ill.

Future AIEE Meetings

North Eastern District Meeting
Lenox, Mass. (Pittsfield Section)
May 18–20, 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., August 9–12, 1938

Southern District Meeting
Miami, Fla., November 1938

Student Branches of South West District to Meet

The annual convention of AIEE Student Branches in the South West District will be held May 6–7, 1938 at Kansas State College, Manhattan. The program will include two technical sessions, a tour of a large cavalry school, and a banquet and dance on Friday, May 6; and on Saturday a technical session and a business meeting.

On Friday, the AIEE Kansas City Section will join the students in a joint meeting. Convention counselor will be Chester Russell (A'29, M'34) acting head, department of electrical engineering, University of New Mexico, Albuquerque.

Use of IES Name, Initials, and Insignia

The Illuminating Engineering Society recently issued a statement regarding the use of the society's name, initials, and insignia in publicity relating to IES lamps. The statement is expected to assist materially in eliminating the unauthorized use of the society's name, and in clarifying the society's position with respect to the lamp activity.

The society is a technical and research body with no commercial interest in the manufacture and sale of any lighting equipment. Specifications for mechanical, electrical, and illuminating features of portable lamps (not "fixtures") intended to supply utilitarian lighting have been made available to manufacturers, but there are no specifications or restrictions covering the decorative and artistic appearance of these lamps. The society requests that no use shall be made of the name, initials, or insignia in connection with the manufacture and sale of portable lamps unless these lamps have been built to meet the society's specifications and properly certified by the approved testing laboratories. It was pointed out that a lamp either meets the specifications or does not, and that there is no such thing as an "IES-type" lamp or an "IES principle." The society also forbids the use of its name or initials as part of the name of any company or association.

AIEE Atlanta Section Becomes Georgia Section

Upon recommendation of the AIEE Sections committee, the Institute's board of directors has authorized a change in name of the Atlanta Section to "Georgia Section," and the extension of its territory to include the entire state of Georgia. The membership of that Section will thereby be increased from some 80 to more than 100 members.

The Atlanta Section was organized January 14, 1904. H. N. Pye (A'15, M'27), chief engineer, South Eastern Underwriters Association, is present chairman of the Section; J. M. Flanigen (A'22, M'25), assistant superintendent, retail operation, Georgia Power Company, is secretary.

Carnegie Tech Receives Gift. A gift of $300,000 from the Maurice and Laura Falk Foundation to the Carnegie Institute of Technology, Pittsburgh, Pa., for the support of a program of education and research in social relations was announced recently by R. E. Doherty (A'16, M'27) president of Carnegie Tech, and former chairman of the AIEE committee on education. In recognition of Mr. Falk's life-long interest in social problems, the foundation will establish at Carnegie a professorship of social relations, and the holder of this position will have charge of the new educational program. Mr. Falk, who established the foundation, pioneered the development of nonferrous industries in the Pittsburgh district and is active on the boards of several steel corporations.

A Pacific Coast Convention Attraction

Photo by George M. Henderson

A trip to Timberline Lodge on the slopes of Mount Hood, some 60 miles from Portland, Ore., may be included on the program of the AIEE 1938 Pacific Coast convention to be held in Portland. Convention dates, August 9–12, are almost a month earlier than those of previous recent conventions in order to provide better opportunity for combined vacation-convention trips.

To Institute Members Planning Trips Abroad

Members of the Institute who contemplate visiting foreign countries are reminded that since 1912 the Institute has had reciprocal arrangements with a number of foreign engineering societies for the exchange of visiting member privileges, which entitle members of the Institute while abroad to membership privileges in these societies for a period of three months and members of foreign societies visiting the United States to the privileges of Institute membership for a like period of time, upon presentation of proper credentials. A form of certificate which serves as credentials from the Institute to the foreign societies for the use of Institute members desiring to avail themselves of these exchange privileges may be obtained upon application to Institute headquarters, New York. The members should specify which country or countries they expect to visit, so that the proper number of certificates may be provided, one certificate being addressed to only one society.

The societies with which these reciprocal arrangements have been established and are still in effect are: Institution of Electrical Engineers (Great Britain), Société Française des Electriciens (France), Association Suisse des Electriciens (Switzerland), Associazione Elettrotecnica Italiana (Italy), Koninklijk Instituut van Ingenieurs (Holland), Verband Deutscher Elektrotechniker E. V. (Germany), Norsk Elektroteknisk Forening (Norway), Svenska Teknologföreningen (Sweden), Stowarzyszenie Elektrykow Polskich (Poland), Elektrotechnicky Svaz Ceskoslovensky (Czechoslovakia), The Institution of Engineers, Australia (Australia), Denki Gakkwai (Japan), and South African Institute of Electrical Engineers (South Africa).

Canadian Electrical Engineer Dead. James Stewart Arbuckle, prominent electrical engineer of Montreal, Que., Canada, died February 4, 1938. Mr. Arbuckle, a native of Pictou, N. S., was graduated from Pictou Academy in 1914, received an engineering diploma from Acadia University, and received the degrees of bachelor of science in electrical engineering and master of electrical engineering at McGill University and Cornell University, respectively. After graduating from Cornell he became associated with the Scintilla Magneto Company, New York, N. Y., remaining with that company until the American Brown-Boveri Electric Corporation was formed at Camden, N. J. At that time he was appointed consulting engineer on mercury-arc rectifiers for the American Brown-Boveri Corporation, and later went to the home offices of the company in Switzerland. Following one year as professor of electrical engineering at North Carolina State College, Mr. Arbuckle was associated briefly with the MacDonald Engineering Corporation, Philadelphia, Pa., as an efficiency engineer. Later he returned to the employ of the Brown-Boveri corporation when that organization established Canadian offices in Montreal. When the Swiss Electric Corporation, Ltd., was organized as a Canadian subsidiary of Brown-Boveri, he became chief

consulting engineer and general sales manager. Mr. Arbuckle was an associate of the AIEE from 1926 to 1932; he was a member of the Engineering Institute of Canada and of several other engineering societies.

Future Meetings of Other Societies

American Association for the Advancement of Science. Summer meeting, June 27–July 2, Ottawa, Can.

American Chemical Society. Semiannual meeting, April 18–21, Dallas, Tex.

American Institute of Chemical Engineers. Semiannual meeting, May 9–11, White Sulphur Springs, W. Va.

American Iron and Steel Institute. General meeting, May 26, New York, N. Y.

American Physical Society. 220th meeting, April 28–30, Washington, D. C.

221st meeting, June 1938, Pacific Coast.

222d meeting, June 24–25, Toronto, Ont., Can.

American Society for Testing Materials. Annual meeting, June 27–July 1, Atlantic City, N. J.

American Society of Civil Engineers. Annual spring meeting, April 20–22, Jacksonville, Fla.

American Society of Mechanical Engineers. Semiannual meeting, June 20–24, St. Louis, Mo.

Association of Iron and Steel Engineers. Annual spring conference, April 28–29, Baltimore, Md.

Canadian Electrical Association. Annual convention, June 22–24, Seigniory Club, Province of Quebec, Can.

Edison Electric Institute. Engineering committees, May 2–5, Chicago, Ill.

Annual convention, June 7–9, Atlantic City, N. J.

Electrochemical Society. Spring meeting, April 27–30, Savannah, Ga.

Institute of Radio Engineers. Annual convention, June 16–18, New York, N. Y.

Joint meeting with American Section of International Scientific Radio Union, April 29–30, Washington, D. C.

International Conference of Naval Architects and Marine Engineers. June 16–18, London, England.

International Engineering Congress. June 21–24, Glasgow, Scotland.

Midwest Power Conference. April 13–15, Chicago, Ill.

National Electrical and Radio Exposition. April 20–30, New York, N. Y.

National Electrical Manufacturers Association. May 15–20, Hot Springs, Va.

National Fire Protection Association. May 9–13, Atlantic City, N. J.

Northwest Electric Light and Power Association. Annual meeting, April 20–23, Vancouver, B. C.

Pacific Coast Electrical Association. Annual convention, May 26–27, San Francisco, Calif.

Society of Automotive Engineers. Annual meeting, June 12–17, White Sulphur Springs, W. Va.

Society of Chemical Industry. Annual meeting, June 20–22, Ottawa, Can.

Engineering Lectures Sponsored by Johns Hopkins

A series of six public lectures is currently being given (Wednesday evenings during March and April) by members of the electrical engineering staff of The Johns Hopkins University, Baltimore, Md. Offered from time to time, these lecture series deal with the practical phases of engineering problems, giving attention to working methods of design, construction, and operation, and especial characteristics of equipment and materials involved. Specifically intended for engineers, foremen, wiremen, and others making practical usage of various forms of electrical equipment, these lectures are open to the general public.

The current series deals with the general subject of electron tubes in engineering:

"Electrons, Their History and Properties," by Doctor J. B. Whitehead.

"Electron Tubes, Types and Characteristics," by Doctor F. Hamburger, Jr.

"Electronic Rectifiers," by Doctor J. H. Lampe.

"Electronic Control in Industry," by Doctor W. B. Kouwenhoven.

"The Electron Tube as Amplifier," by Doctor F. Hamburger, Jr.

"Electron Tubes in Radio Communication," by Doctor F. Hamburger, Jr.

Industrial Research Laboratories. A new edition of the National Research Council's bulletin, "Industrial Research Laboratories of the United States," has been made desirable by the recent increase in the number of research laboratories maintained by industrial concerns. Questionnaires have been sent to many concerns, and an appeal is made to those who are employed by firms which maintain laboratories to ascertain if a questionnaire has been received; a questionnaire may be obtained from the library, National Research Council, 2101 Constitution Avenue, Washington, D. C. No charge is made for an entry in the bulletin.

Noted Bridge Builder Dies. John Alexander Low Waddell, one of the best known of American bridge builders, died at New York, N. Y., March 3, 1938. Doctor Waddell was born at Port Hope, Ont., Canada, January 15, 1854, and was graduated from Rensselaer Polytechnic Institute in 1875. Throughout his career he received many honorary degrees from educational institutions in the United States and foreign countries. Following his graduation in 1875 he became engaged in railway work, following which, in 1881, he became chief engineer for Raymond and Campbell, bridge builders, of Council Bluffs, Iowa. In 1882 he went to Japan, where for four years he was professor of civil engineering at the Imperial University at Tokyo. Upon his return to the United States, Doctor Waddell opened a consulting-engineering office in Kansas City, Mo., continuing there in the practice of bridge engineering until 1920, when he moved his offices to New York. Doctor Waddell was acknowledged to be the originator of the modern vertical lift bridge, his first structure of that type being the Halstead Street Bridge, built in 1895 in Chicago, Ill. Twice he was consulted professionally by the Chinese government: In 1921 as the American member of an international commission for reviewing the designs for a proposed bridge over the Yellow River; and in 1929 as a consulting engineer to the Ministry of Railways.

AIEE New Orleans Section Inspects Sulphur Plant

On February 12, 1938, members of the AIEE New Orleans Section staged an inspection trip to the plant of the Freeport Sulphur Company at Port Sulphur, La. A group is shown here inspecting some of the material-handling equipment. This photograph was made available by A. S. Anderson, member of the New Orleans Section and District vice-chairman of the national membership committee.

Membership—

Mr. Institute Member:

Membership in the Institute confers upon the older men in the profession the privilege of becoming acquainted with and providing inspiration to the younger men, who must be continually coming in from the lower ranks. Similarly, those young men who join the Institute have the opportunity of becoming acquainted with the older men in the profession on a basis of friendship, co-operation, and common aims. It is a rare privilege to an older man to feel that he has helped a young man to greater effort and more praiseworthy endeavor as it is an inspiration to the younger man to have a personal acquaintance and friendship with the men who may otherwise be beyond his immediate hope of acquaintance.

Each member of the Institute can perform a valuable service to his profession by being instrumental in bringing these two groups of men—the old wise heads and the young men just starting out—to a closer relationship in friendship and co-operation by helping to bring them into the Institute.

Wilson R. Lovegrove

Vice-Chairman District No. 6
National Membership Committee

A membership proposal form appears on page 18 of the advertising section of this issue

Procedure Handbook of Arc Welding Design and Practice, fifth edition ($1.50), recently announced by The Lincoln Electric Company, Cleveland, Ohio, contains 1,012 pages and a total of 1,243 illustrations. The Handbook is reissued each year to include all new data essential for most efficient use of arc welding in all its varied applications. Encyclopedic in scope, concisely written and profusely illustrated, the Handbook is a comprehensive arc welding reference guide. Written especially for the use of designers, engineers, architects, production managers, welding supervisors and operators, the Handbook contains a wealth of data of interest to draftsmen, steel fabricators and erectors, foremen, cost estimators, maintenance managers, shipbuilders, piping and pipe line contractors and students of welding.

Current Items From American Engineering Council

Technology, a Great National Resource

The eighteenth annual assembly of the American Engineering Council has approved the following findings of its special committee on scientific research legislation. In so doing, Council is believed to have voiced the sentiment of all of those engineers who realize that technology is our greatest national resource in terms of employment and economic stability and that fundamental research in the broad field of technology is essential to the advancement of modern civilization.

"Engineering and scientific research advances the standard of living by creating new products and discovering means for bringing old products within the purchasing power of more people. New industrial, commercial, and agricultural enterprises originating in such discoveries and inventions provide a sound basis for that continuous expansion of opportunity for employment of an increasing population which is so vital to economic stability.

"Co-ordinated and scientifically directed research is essential to the maintenance of adequate national defense, and persistent technical inquiry into the fields of biology, chemistry including food technology, public health, and medical science affords added protection against the natural and human hazards of a complicated civilization. In fact, all experience with research has proven it to be an investment in the public welfare.

"Engineers, individually and collectively, recognize their responsibility in the realm of technology and hold a profound desire to support all phases of research having a realistic objective, to the end that such valuable contributions to all important public service purposes may be attainable.

"American Engineering Council in its eighteenth annual assembly announced its belief and confidence in the following principles and requested its special committee on scientific research legislation to continue a study of possibilities for the Federal Government to aid research in the technology as well as in the pure and applied sciences.

"1. *Purpose of Research Activity.* Continued and aggressive attention must be given to many problems of a fundamental scientific and engineering nature by carefully planned research, to secure:

"*a.* The establishment of new industries;

"*b.* The expansion of existing industries;

"*c.* The increase of employment in industry, commerce, and agriculture;

"*d.* The wider distribution of the products of industry through reductions in cost, as a step toward higher standards of living especially for those of moderate and small income.

"*e.* The furtherance of public health and public safety by the applications of science in wisely planned engineering works and methods; and

"*f.* A firmer scientific and technical basis for national defense.

"2. *Federal Aid Necessary.* In order that the benefits of research may be most promptly realized by the public, the aid and encouragement of the Federal Government should be provided in all proper ways, including: (*a*) prosecution of more such fundamental research by present federal bureaus and establishments; (*b*) stimulation and assistance for research at educational institutions and such nonprofit-making laboratories as may be best prepared to serve the public; and (*c*) encouragement of all industrial and individual effort on research projects to the end that the maximum in useful results may be obtained at the earliest feasible date, regardless of the agency which sponsors or carries out the work involved.

"3. *Education Aid Required.* Since the training of persons fitted by knowledge and temperament to become research workers is an important responsibility of the public generally, it should be an important part of the duty of the Federal Government to aid present educational institutions in the enlargement and improvement of their facilities for graduate training of students in research methods and the preparation of such competent young people for a career in engineering and scientific research, both that of government and state agencies and in private employment.

"4. *No Interference With Private Enterprise.* Participation by the Federal Government in research projects should be so limited as not to interfere with present or prospective research of individuals, corporations, or educational institutions. If suitable precautions to this effect are not taken, the benefits of new public effort might be less than the benefits otherwise to be anticipated from the other research interfered with. Under wise technical management, the encouragement of research with federal funds need not interfere with any other type of scientific or engineering investigations."

Standards

Standardization of Bushings. In pursuance of a recommendation of the committee on co-ordination of Institute activities, the standards committee on February 25 appointed R. T. Henry as chairman of a subcommittee to consider the standardization of the electrical characteristics of bushings. Coupling capacitors are also to be included in the scope of work. The proposed subcommittee not only will include in its personnel, representatives of the several Institute committees involved, but also will be made up of essentially the same people as appear on the interested ASA committees. With this set-up it is felt that whatever the committee may eventually report will be satisfactory to all interests.

Rating and Recommendations on Operation. In a report by P. L. Alger presented to the standards committee on February 25, the suggestion was made that a review should be undertaken of the problems involved in the rating of electrical apparatus. In general such a review would consider such questions as effect of permissible temperature rises on life of apparatus, data now available on the life of insulation and new types of insulation, specified methods of temperature measurement, and continuous rating and its bearing on apparatus life. Data may well result from such an undertaking as will enable a user to determine how fast he is using up his apparatus. It was felt that perhaps the most effective way of arriving at definite results in regard to the problems involved would be through the holding of a symposium at an Institute meeting. Chairman Montsinger and Mr. Alger were delegated therefore to present at the next meeting of the technical program committee a complete picture of what the standards committee has in mind. The feasibility of such a symposium or other appropriate action can then be determined.

Automatic Stations. The sectional committee on power switchgear late in 1937 completed a revision of the "Standard for Automatic Stations." The basis of their work was the AIEE standard on the same subject of May 1930 which the Institute had submitted to the American Standards Association for action, together with a revision of the 1930 edition drawn up by the AIEE committee on automatic stations. The new standard, now under the sponsorship of the electrical standards committee, received approval of ASA as an American standard in October 1937. In addition to definitions, the new automatic-stations standard contains a complete list of standard device function numbers and a tabulation of the minimum protective device requirements for all of the principal classes of machines and equipment controlled by automatic switchgear. It has been found possible to assign definite numbers to all devices used in automatic stations on the basis of the function to be performed, these numbers being used uniformly by all manufacturers. The automatic stations standard, No. *C37.2*, is now available in pamphlet form at a cost of 40 cents per copy with the usual 50 per cent discount to AIEE members on single copies. Orders should be addressed to AIEE headquarters, attention of H. E. Farrer.

Oil Circuit Breakers. At the February 25 meeting of the standards committee of the Institute, approval was given to a revision of the present AIEE standard No. 19 for "Oil Circuit Breakers." This revision was submitted by the Institute's committee on protective devices. It was pointed out that a subcommittee of the sectional committee on power switchgear is at work on the development of an American standard for oil circuit breakers, but that because of the necessary procedure involved in obtaining approval, a considerable time would elapse before their work would be available to industry. As the AIEE report is identical, as far as it goes, with the proposed ASA standard and contains new material of vital interest to users, it seemed desirable to make it available by giving it formal AIEE approval and publishing as soon thereafter as possible. The report will therefore be submitted to the board of directors for action at their next meeting and then issued in pamphlet form without delay.

Relays. A standard for "Relays Associated with Power Switchgear" has been completed by the sectional committee on power switchgear. The basis of this new standard was the revised AIEE Report on Relays, No. 23, as submitted to ASA by the Institute. The standard is not limited to electrically operated relays, but also covers temperature relays, pressure relays, etc. However, it governs only relays directly associated with power switchgear. Relays associated with industrial control equipment, excitation or governor regulating equipment, and relays used for telephone, telegraph, traffic and railway signals, have to meet other requirements. For that reason they are not included. The new relay standard, No. *C37.1*, is now available in pamphlet form at a cost of 40 cents per copy with the usual 50 per cent discount to AIEE members on single copies. Orders should be addressed to AIEE headquarters, attention of H. E. Farrer.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

The Dielectric Circuit

Editor's Note: A faulty inference in the statement that "In some dielectrics a given charge of electricity may produce from one to ten times the force action that is produced in air," in the recent article by D. D. Ewing (*EE, Dec. '37, p. 1435*, third full paragraph, left-hand column) has been cited by William Kober (A'32) as a contradiction of Coulomb's law. Professor Ewing comments on the error as follows.

To the Editor:

There is a just reason for this criticism, because apparently I did not make the point under discussion clear. The paragraph criticized was not meant to refer to Coulomb's law, but rather to the experimental relation which I arbitrarily called the "fourth experimental law."

I had originally written in this paragraph an illustration drawn from the magnetic circuit, but in the interest of brevity I deleted it and in this process inadvertently used a wrong quantity. The sentence under discussion should have read "a given potential between capacitor plates" instead of "a given charge of electricity."

I was trying to emphasize the idea here that just as the insertion of an iron core in a solenoid will increase the magnetic pull, so will the insertion of certain materials in a dielectric circuit increase the force action between certain parts of the circuit. Apparently when I deleted my illustrative material I ruined the paragraph from the standpoint of clarity.

Very truly yours,
D. D. EWING (A'11, F'21)
(Professor of Electrical Engineering Purdue University, Lafayette, Ind.)

Registration of Engineers

To the Editor:

We wish to call attention to, and protest the publication of the letter or similar letter to that published on page 42 of January 1938 issue of ELECTRICAL ENGINEERING magazine, signed by Mr. Louis S. Leavitt.

Mr. Leavitt may, for some personal reason, not approve of the methods of handling the "registration" of engineers in his territory.

To condemn the whole proposition and persons and technique as a "racket" is certainly not an "ethical engineering report."

We question the ethics of publishing a letter in our engineering magazine containing the unsupported charges as written in the third paragraph of the above-mentioned letter.

We feel that the editors of ELECTRICAL ENGINEERING should not allow such a letter to be published unless there are very complete supporting data and it is intended that the AIEE, as an organization,* believes that the charges are justifiable. As a matter of fact, it is our understanding that the AIEE supports the idea of state registration laws.*

In justice to the engineers, who have given much of their time and ability toward the upbringing of the engineering provision of registration, we believe a retraction and statement of the position of the AIEE on this subject should be made.*

The paragraph referred to above is an example of the "unethical lowly ethics" supposedly condemned by Mr. Leavitt.

Very truly yours,

M. C. GOODSPEED (A'10, M'12)

(Safety Engineer, General Electric Company, Erie, Pa.)

*Editor's Note: Attention is called to the conditions governing the publication of Letters to the Editor, as posted at the head of these columns. This department is merely a forum for the expression of readers' opinions on matters presumably of some current interest. The question of registration laws has been left as a matter of local option for the various sections.

To the Editor:

In the January 1938 issue of ELECTRICAL ENGINEERING there is published a letter from Louis S. Leavitt, which is supposed to be on the subject of "registration of engineers," however, the author states that he "knew practically nothing about its operation" and begins one sentence "I venture to guess." Mr. Leavitt then proceeds to inform your readers of the existence of "a board of politicians" and "nice fat political jobs" and suggests "that if real unsavory conditions have developed, a backfire aimed at removing the law from the books can be started and fanned into a real blaze." As no such law is in effect in the state of Massachusetts, it is evident that Mr. Leavitt is trying to dictate to engineers in other states how they should regulate the practice of their profession.

The writer has been an officer of the National Council of State Boards of Engineering Examiners for almost fifteen years and has had the privilege of being associated with the majority of the members of all of the state boards of engineering examiners or registration and he knows positively that they are not politicians, engineering or otherwise, and are not holding fat political jobs but are unselfish, intelligent gentlemen, serving the engineering profession and the public with very little remuneration or appreciation for their services except the satisfaction of a deed well done.

If Mr. Leavitt is sincere in his desire for information on the subject of the legal registration of engineers and will accept such information in a fair and unbiased manner, we hope he will read the four pamphlets we have mailed to him.

It is also suggested that Mr. Leavitt and your magazine might secure some pertinent facts from such members of AIEE as Doctor Charles F. Scott, past-president, AIEE; vice-president of the National Council of State Boards of Engineering Examiners and chairman of the Connecticut State Board of Registration for Professional Engineers and Land Surveyors; Dean P. H. Daggett, past-president of the National Council and chairman of its committee on accredited engineering schools; and Professor J. O. Kammerman, director of the National Council and a member of the South Dakota State Board of Engineering and Architectural Examiners.

It is assumed, of course, that in fairness to all concerned your magazine will give the same publicity to this communication and to the letters to you from Mr. F. O. Runyon and Mr. Willard S. Conlon as was given to the letter from Mr. Leavitt.

Very truly yours,

T. KEITH LEGARÉ

(Executive Secretary, National Council of State Boards of Engineering Examiners, Columbia, S. C.)

Pareto—Engineer, Economist, Sociologist

To the Editor:

In line with the current discussion of the place of the engineer in society, it is of interest to note the life and works of one who went from the practice of engineering to the study of economics and then of sociology. The life and works of Vilfredo Pareto are suggested as a guide in the enlarging concept of engineering because in his progression from mechanical matters to those of a sociological nature, he retained the scientific method which has been so outstandingly successful in the mechanical sciences.

Pareto was born in Paris, later moved to Italy, and attended the Polytechnic School at Turin. For twenty years he did engineering work relating especially to railways. At the age of forty-five he joined the University of Lausanne as professor of political economy. It was because he felt that economic theories were not alone sufficient to explain various phenomena in that field that he turned his attention to sociology. The results of his researches are contained in a translation entitled "The Mind and Society."

This theory is advanced as a scientific one, as using fundamentally the same method employed in the physical sciences. What is meant by scientific the author defines at length. His cornerstone in formulating scientific sociological laws he stresses is observation and experience. This is second nature to the engineer in regard to the mechanical sciences, but in economics and sociology there is great danger of overstepping the bounds of experience whether by the use of vague or abstruse terms or by the introduction of metaphysical elements. Pareto's theory is based on observation of facts, things that can be perceived by the senses. By an inductive process building up from the observation of facts, laws are formulated. A scientific law, according to the Paretan concept, is merely descriptive, a pithy summarization of a condition uniform to concrete situations of a specified kind. A scientific law derives from facts, has no validity otherwise, is only as accurate as the observations, and holds good only so long as no one turns up with an observation contrary to what the law describes. The things observed determine what science is developed. If one observes the effect of voltages on insulating materials he develops a theory of dielectrics, part of electrical science. Pareto observed the actions of men and developed sociological science.

To illustrate the definition two examples are given. A transmission line calculation is based on scientific laws which, though complex, are based on objective things. Back of these laws are standards such as a resistance of one ohm and processes which can be defined exactly and in any language. Every term used in the statement of these laws can be demonstrated by dispassionately going through a process or by pointing to a physical object which is a standard. Having made the calculation, the results, after the completion of the line, are measurable.

The law of evolution in so far as it describes a series of forms of life is scientific, but when there is implied a purpose or design behind such successive forms, then the theory transcends science as Pareto defines it simply because the alleged purpose or design, whatever our feeling about the matter, is not a matter of experience.

The method which Pareto employs is that which was used in the formulation of electrical laws, as an example, and he is careful to avoid the departures from experience which many theories represent. He admits frankly that there are other possible methods of studying the actions of men than his experimental method, states that his basis of observation and experience is simply axiomatic, and affirms his intention of being rigorously consistent with that basis throughout.

So much for Pareto's method. What is the theory itself? It can be only hinted at here. In the first place he divides the actions of men into two classes, those that are based on scientific or, in other words, experimental theories and which we will call logical actions, and those that are based on nonexperimental theories and which we will call nonlogical actions. An example of this distinction is the case of the ancient Greek sailors who in advance of a voyage made sacrifices to one of their gods and then rowed to their destination. We have observed that rowing is an effective means of causing a boat to move but have observed no connection between the making of sacrifices and the navigation of a boat. To the Greek sailors, however, both methods were necessary and effective for the making of a safe voyage. Rowing is to us a logical action, the offering of sacrifices a nonlogical one. It should not be inferred from the example that nonlogical actions are of trivial importance. In our own times there are many myths, although not referred to as such, which affect our society in important ways.

It is a human urge to try to give logical explanations to events including the actions of other persons, but much conduct that is made to appear as if persons were acting logically is in fact based on nonlogical principles. We might be inclined to treat the mythological beliefs of the Greek sailors as absurd prejudices and having thus done away with these beliefs only the logical

matter of rowing would remain. One cannot, however, thus sweep away such nonlogical conduct if he would understand the forces at work in society. We could appreciate the importance of nonlogical conduct if we should wonder what a future historian would have to say about the nineteen thirties.

Interests, or in other words, one's relation to his daily bread and other commodities, does not explain the whole story. It does not explain, for example, why one person gains his bread by the practice of medicine while another gains his through politics. Interests are important but not the sole elements in conduct.

Having determined that nonlogical actions were both common and important in society Pareto classified them. He found in certain groups of actions an element which was common to all individual cases within that group. And here we come back, by way of example, to the Greek sailors about whom it is easy for us to be objective. He observed that they made sacrifices to one of their gods in advance of a voyage. He observed other instances of the ancient Greeks propitiating their gods and treating them as real entities. Common to all these observations is the persistence of personifications, which he calls a residue although the name itself has little significance. Personifications come under a classification called the persistence of aggregates, which, in brief, reflects an attitude toward perpetuating organizations, abstractions, etc. Another broad classification reflects faith in combinations of things. It is here that the scientist is represented. In general, the persistence of aggregates group includes the conservatives, the combinations classification the inventors, devisers, and schemers. Other groups can be characterized as the impulse to action, sociability, and the integrity of the individual. Strictly these residues are what one gets by following a certain specified process just as power factor is what results when you read certain meters and make calculations in a given way. The residues have been described, however, as "inner drives."

One of these drives is that of rationalizing one's actions. Measures may be advance, for example, with the reason given that they are in accordance with "time honored custom," "sound principles," or the thoughts of "all intelligent persons." Such methods which have been devised to logicalize present or prospective actions cover a wide range, but searching analysis based upon the norm of experience can grant them no validity. The methods include the appeal to the authority of men or customs, accord with sentiment, and the use of ambiguous terms. An important clue to the residues or inner drives is afforded by these attempts to rationalize nonexperimental theories, such rationalization not being taken at their face value but merely viewed as occurrences.

The residues change slowly but the devices used to objectify them shift more rapidly. An example of this point is the State as expressing a concept which includes something intangible over and above an observable collection of individuals and a geographical territory. It may be a valuable concept but it does not come wholly within the realm of observation and experience. It is an objectification of sentiment by by means of a label. The concept of State has come down from ancient times but the attempts to make that concept objective have varied. In ancient times State was conceived as exemplifying Justice, was later accompanied with the social-contract theory, and in recent times was viewed as the asymptote of a progression—the family, the clan, the tribe, etc.

Pareto's works include descriptions of how residues function in society, what happens when their equilibrium is disturbed, the utility of the residues in society. He supports his findings here as in other parts of his theory with numerous examples.

The above has merely touched at points of this extensive work in an attempt to indicate the analysis and method rather than to summarize. The examples given have been for the purpose of clarity and have been deliberately taken as far from our present concerns as possible in order that they might be viewed objectively.

A few comments will be made on the nature of the theory. In the first place, it is not a mechanical analogy although the method used is the same in principle as that used in the physical sciences. It is not a glorification of Science in that it does not claim anything that cannot be supported by experience applied at every point. It promotes no "ism," no particular social system. Its relation to psychology is analogous to a person taking a value for transformer efficiency and using that in computing the efficiency of a transmission line including transformers. He does not need to know all the ins and outs about the transformer efficiency beyond the division between core and copper losses. Pareto's sociology is analogous to the over-all transmission calculation, the detailed computation or measurement of the transformer efficiency to psychology.

The theory contains many points which are not new as isolated observations but what is new is their correlation and combination in a significant way. The laws developed have the value of epitomizing otherwise complex phenomena as alternating current laws summarize what, except for these laws, would be isolated unrelated data.

If the engineer is to understand more of social forces, he can do so on his own objective experience basis by using Pareto as a guide. The engineer is in the position of having had scientific training and is familiar with the experimental method. He is fitted by training to distinguish that which is known on the basis of experience from that which is not, two realms of thought and feeling which are constantly being confused although each has its proper sphere. The engineer is noted for his consistent results in physical matters. Careful consideration should be given to social engineering if he is to be similarly effective in that field.

Very truly yours,

EVERETT L. SWEET (A'25)
(Central Hudson Gas and Electric Corporation, Poughkeepsie, N.Y.)

Personal Items

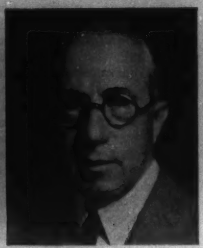
G. H. BUCHER (M'24) executive vice-president of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was elected president of the company. Mr. Bucher was born July 24, 1888, at Sunbury, Pa., and is a graduate (1909) of Pratt Institute. Following his graduation he was employed by the Westinghouse company at East Pittsburgh as a graduate student. In 1911 he was transferred to the export department of the company in New York, N. Y., and in 1920 was appointed assistant to the general manager of the Westinghouse Electric International Company. In the following year Mr. Bucher was made assistant general manager which position he held until 1932, when he was elected vice-president and general manager. In 1934 he was elected president and general manager of the Westinghouse Electric International Company, and in the following year became vice-president of the Westinghouse Electric and Manufacturing Company. He was appointed executive vice-president in 1936.

W. H. SAMMIS (A'20) assistant to the vice-president of the Commonwealth and Southern Corporation, New York, N. Y., recently was elected a vice-president and director of the corporation. Mr. Sammis was born at Hempstead, N. Y., June 28, 1896, and was graduated from Columbia University in 1917 with a degree in electrical engineering. Following his graduation he became a machinist and ensign in the United States Navy, serving as an instructor at the naval training school at Great Lakes, Ill. After serving one year as an instructor at Columbia University Mr. Sammis became a member of the Consumers Power Company, Jackson, Mich., in 1920, and six months later was made assistant electrical engineer, subsequently becoming power sales engineer. In 1924 he became affiliated with C. H. Tenney and Company of Boston, Mass., for power sales and rate-analysis work on the properties of that company located in New York and New England. In the following year he returned to the Consumers Power Company as assistant to the general manager, and in 1929 became assistant to the president. In 1932 he was made a vice-president and director of the company and was elected president of the Pennsylvania Power Company in 1936. Mr. Sammis still retained his positions in the Consumers Power Company and the Pennsylvania Power Company both of which are operating units of the Commonwealth Southern Corporation.

H. C. DEAN (A'12, F'30) vice-president of the New York and Queens Electric Light and Power Company, Long Island City, N. Y., recently was elected vice-president

G. H. BUCHER

W. P. HOLCOMBE



F. A. MERRICK

and assistant to the vice-chairman of the board, in which position he will assume the duties of local administrative officer of the company. Mr. Dean was born at Canton, S. D., March 25, 1888, and was graduated from the University of Illinois in 1909 with the degree of bachelor of science in railway electrical engineering. After three years with the Public Service Company of Northern Illinois he entered the employ of the City of Chicago, and in 1914 became electrical engineer in charge of the Bureau of Engineering and Construction in the Department of Gas and Electricity. In 1916 he became affiliated with the New York and Queens Electric Light and Power Company, with the position of assistant to the vice-president, and in the following year Mr. Dean was appointed general superintendent in charge of the engineering, construction, operation, and transportation departments of the company, continuing in this position until his appointment as vice-president in 1934. In 1935 he was elected a director of the company and also became a member of its executive committee. Mr. Dean was a member of the Institute's Board of Examiners from 1933 until 1937 and served as chairman during 1936–37. Until recently he was a member of the committee on legislation affecting the engineering profession and served on the power transmission and distribution committee from 1929 until 1932.

SIR JOHN SNELL (A'06, F'12) former chairman of His Majesty's Electricity Commissioners, London, England, has been awarded the Faraday Medal of the Institution of Electrical Engineers (Great Britain). The medal is awarded not oftener than once a year for notable scientific or industrial achievements, or for conspicuous service rendered the advancement of electrical science. Sir John was born December 15, 1869, at Saltash, Cornwall, and was educated at King's College in London. For three years he was assistant engineer for Crompton and Company, in which position he became engaged in central-station work in both England and Sweden. He then became chief assistant to a consulting engineer for three years before being appointed resident engineer for the Borough Council in London. Sir John was borough electrical and tramways engineer to the Sunderland Corporation for nine and one-half years before becoming a partner in the firm of Preece, Cardew, and Snell in 1906. He continued in private consulting work until 1918. During 1914–15 he was president of the Institution of Electrical Engineers, and from 1926 until 1931 was a vice-president of the Institution of Civil Engineers. Sir John is a past member of the British Advisory Council for Scientific and Industrial Research, has been chairman of the water power resources committee, and chairman of the committee on electroculture of the Ministry of Agriculture. He retired as chairman of the Electricity Commission at the end of 1937.

W. P. HOLCOMBE (A'06, M'13) vice-president of the Brooklyn Edison Company, Inc., Brooklyn, N. Y., recently was elected vice-president and assistant to the vice-chairman of the board, in which position he will assume the duties of the local administrative officer of the company. Mr. Holcombe was born at Mobile, Ala., November 20, 1875, and was graduated from Centenary College with the degree of bachelor of science in 1896. Later he enrolled in the graduate school of electricity and mechanics at Alabama Polytechnic Institute, but his graduate studies were interrupted by his enlistment in the United States Army at the beginning of the Spanish-American War. After the War he became affiliated with the Mobile Electric Company, with which he remained until 1903, when he went to St. Louis, Mo., with the Wesco Supply Company. Later Mr. Holcombe joined the sales department of the Frank Adam Electric Company of that city. In 1919 he went to Detroit as engineer and partner in an electrical contracting company, and in 1920 he joined the Brooklyn Edison Company as purchasing agent. Mr. Holcombe was elected vice-president in 1926.

F. A. MERRICK (A'07) since 1929 president of the Westinghouse Electric and Manufacturing Company, recently was elected vice-chairman of the board. Mr. Merrick was born at Lambertville, N. J., and was educated at Lehigh University, where he was graduated in 1891 with a degree in electrical engineering. In the same year he entered the employ of the Thomson-Houston Electric Company and served successively as a consultant with the engineering firm of Blood and Hale, manager and chief engineer of the Steel Motors Company. When the Steel company was absorbed by the Westinghouse Company in 1902, Mr. Merrick was retained by the latter. In the following year the Canadian Westinghouse Company, Ltd., was formed and Mr. Merrick was sent to Hamilton, Ont., to take charge of the construction of the company's plant there. He remained as superintendent and later became successively manager, vice-president, general manager, and director. During the World War he was placed in charge of the factory of the New England Westinghouse Company at Chicopee Falls, Mass. After the War Mr. Merrick was located in London, England, for two years as special representative of the Westinghouse Electric International Company, after which he returned to Canada to resume his duties as vice-president and general manager of the Canadian Westinghouse Company. He was elected president of the Westinghouse Electric and Manufacturing Company in 1929.

W. H. SAMMIS

Bachrach

H. C. DEAN

SIR JOHN SNELL

C. C. CURTIS (M'23) for the last eight years personnel director of the Engineers Public Service Company at the Stone and Webster Service Corporation, New York, N. Y., has been elected president of the Savannah Electric and Power Company, Savannah, Ga. Mr. Curtis was born March 27, 1883, at Battle Creek, Mich., and was graduated from the University of Michigan with the degree of bachelor of science in mechanical engineering in 1907. Immediately following his graduation he became associated with the Stone and Webster company as student engineer on a power-station construction project at Lowell, Mass., later going to Pawtucket, R. I.

in the same capacity. For almost five years he served as light and power superintendent and later as general superintendent and manager of the Ponce Railway and Light Company at Ponce, Porto Rico. He then returned to New England to the Stone and Webster Boston, Mass., offices, but in 1913 he went into the field again as an executive for the Lake Ariguanabo Company in Cuba. Later in the same year Mr. Curtis returned to the United States and was made superintendent of the Houghton County Electric Light Company, Houghton, Mich., where he remained until 1915. From 1915 until 1918 Mr. Curtis was superintendent of the light and power department of the El Paso Electric Company, El Paso, Tex., before going to Sydney, Nova Scotia, as manager of the Cape Breton Electric Company, Ltd. From 1923 to 1931 he was vice-president and manager of the Fall River Gas Works and then was transferred to the division managership of the Puget Sound Power and Light Company, Seattle, Wash. He became personnel director for Stone and Webster in 1931.

JOSEPH SLEPIAN (A'17, F'27) consulting research engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed an associate director of the Westinghouse research laboratories. Doctor Slepian was born at Boston, Mass., in 1891, and received the degrees of bachelor of arts, master of arts, and doctor of philosophy from Harvard University. After a year of study in Germany and France he was appointed to the faculty of Cornell University as an instructor in mathematics, remaining there until he entered the student course of the Westinghouse company in 1916. He joined the research department in 1917, shortly thereafter being given charge of the development of electrolytic capacitors. In 1921 Doctor Slepian devised the autovalve lightning arrester, and as a result of his researches on arcs later produced the deionizing circuit breaker. He holds numerous patents and has written many Institute papers. Doctor Slepian has been a member of the Institute's basic sciences committee since 1924, and was chairman of that committee during 1933–34. He has served also as a member of the committee on electric welding and the technical program committee.

C. A. POWEL (M'20, director) manager of the central station engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the newly formed industry engineering department, which has been established to centralize electrical engineering activities of the company relating to central station and industrial power problems. Mr. Powel was born at Rouen, France, July 29, 1884, and was graduated with the diploma of electrical engineer from the Bernese Technical College (Switzerland), following which he entered the application engineering department of Brown, Boveri, and Company in Baden, Switzerland. Six years later he was sent to Japan as resident engineer for that firm and remained there until 1915, when he returned to England and joined the civil branch of the Ordnance Department, during the World War. Following the War Mr. Powel moved to Pittsburgh and joined the Westinghouse company as a general engineer. He is a director of the Institute and a member of the committees on power generation and application to marine work.

W. H. COLE (A'12) for 25 years superintendent of the street engineering department of the Edison Electric Illuminating Company of Boston, Boston, Mass., recently retired from active service. Born June 1, 1875, at Cambridge, Mass., Mr. Cole entered the testing department of the General Electric Company, Lynn, Mass., in 1895, where he remained for three years before becoming chief electrician of the Newton and Watertown Gas Lighting Company at Newton, Mass. In 1906 he became superintendent of the electrical department of the Waltham Gas Light Company, Waltham, Mass., remaining there until 1909. In the latter year he was appointed Waltham agent for the Edison Electric Illuminating Company of Boston, and a few months later was appointed superintendent of the street engineering department and transferred to the Boston offices of the company. Mr. Cole served for many years on the cable committee and as chairman of the underground systems committee of the former National Electric Light Association. He was active also in committee work of the Association of Edison Illuminating Companies.

C. D. POEY (M'37) illuminating engineer and manager of the lighting bureau of the Consolidated Edison Company of New York, Inc., New York, N. Y., recently resigned to become chief engineer of the illuminating division of the Greist Manufacturing Company, New Haven, Conn. A native (1897) of Flushing, N. Y., Mr. Poey attended Yale University and Stevens Institute of Technology before becoming a lieutenant (junior grade) in the United States Navy during the World War. In 1919 he became a sales engineer for the Benjamin Electric and Manufacturing Company, New York, N. Y. Two years later he became affiliated with the Consolidated Edison systems as illuminating engineer for the New York and Queens Electric Light and Power Company. Mr. Poey has been active in committee work of the Illuminating Engineering Society, and has presented many papers on lighting and its applications before that society.

R. D. EVANS (A'21, M'26) central station engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and current chairman of the Institute's committee on power transmission and distribution, recently was appointed a consulting transmission engineer for the company. Mr. Evans was born in 1892 at Spring Water, Wis., and was graduated from the University of Oklahoma in 1914, following which he entered the employ of the Westinghouse Company as a general engineer. He has been affiliated with that company continuously, and has done much original work in studies of power generation and transmission, a-c railway engineering, electric furnaces, and inductive co-ordination. Mr. Evans has served the Institute as a member of the power transmission and distribution committee since 1924, and was a member of the committee on communication from 1924 until 1934.

A. A. LOW (M'37), vice-president of the Consolidated Edison Company of New York, Inc., New York, N. Y., and of Brooklyn Edison Company, Inc., Brooklyn, N. Y., recently was elected vice-president of the New York and Queens Electric Light and Power Company, Long Island City, N. Y. Mr. Low was born at Saratoga Springs, N. Y., in 1889, and received the degree of bachelor of arts at Yale University in 1911. He entered the public utility field in 1928 as organizer and president of the Old Forge (N. Y.) Electric Company. In 1931 he became affiliated with the Utica (N. Y.) Gas and Electric Company as executive vice-president, which position he held for three years before being elected president of that company in 1934. Mr. Low became identified with the Brooklyn Edison Company in 1936 as executive vice-president in responsible charge of operations.

C. F. WAGNER (A'20, M'27) central station engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was appointed a consulting transmission engineer. Mr. Wagner was born in 1895 at Pittsburgh, Pa., and was graduated from Carnegie Institute of Technology in 1917 with the degree of bachelor of science in electrical engineering. Immediately following his graduation he joined the Westinghouse company as an assistant in the engineering laboratory. Since 1924 much of his work has been concerned with power transmission, particularly problems in stability. Mr. Wagner has presented several papers before the Institute and was a member of the committee on power transmission and distribution from 1930 until 1932.

G. B. HULSE (M'22) chief engineer of the Safety Car Heating and Lighting Company, New Haven, Conn., recently was elected treasurer of the American Society of Refrigerating Engineers. Mr. Hulse was born at Bellport, N. Y., in 1877, and was graduated from Stevens Institute of Technology in 1902 with the degree of mechanical engineer. He became affiliated with the Safety Car Heating and Lighting Company at Jersey City, N. J., immediately following his graduation, and has held successively the positions of assistant engineer, engineer of tests, and chief engineer.

DOUGLAS ROBERTSON (A'27) central station engineer for the Canadian General Electric Company, Ltd., Vancouver, B. C., Canada, has been appointed British Columbia

branch manager of that company, with headquarters in Vancouver. A native (1896) of Toronto, Ont., and a mechanical engineering graduate (1918) of the University of Toronto, Mr. Robertson became associated with the Manitoba Power Company in 1921. A year later he joined the engineering staff of the Winnipeg Electric Company, and in 1924 joined the Winnipeg staff of the Canadian General Electric Company, Ltd. In 1926 he was transferred to the Vancouver office, where he has remained since that time.

BERNARD LESTER (A'06, M'13) assistant industrial sales manager, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was appointed manager of the newly formed resale department of the company. Mr. Lester was born in England, in 1881, and was graduated from Haverford College with the degree of bachelor of science. He entered the employ of the Westinghouse Electric and Manufacturing Company in 1906 as assistant manager of the industrial and power division of the sales engineering department, and has been closely identified with the sales work of that organization for more than 30 years.

A. C. MONTEITH (A'25) general engineering department Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has become engineering manager of the central station section of the company. A native (1902) of Brucefield, Ont., Canada, Mr. Monteith has been associated with the Westinghouse company since he was graduated from Queens University in 1923. He completed the Westinghouse graduate student course in 1924 and at once became engaged in central station engineering work.

BYRON ELDRED (F'30) consulting research engineer, New York, N. Y., has been elected president of the Engineers' Club (New York) for the year 1938. Doctor Eldred is a graduate of Dartmouth College in the class of 1896, and has been engaged as a research consultant in New York since 1903. He is a member of The American Society of Mechanical Engineers and the American Institute of Mining and Metallurgical Engineers.

G. E. STOLTZ (A'13, M'19) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the metal working section of the company. Born at Gettysburg, Ohio, in 1886, Mr. Stoltz was graduated from The Ohio State University in 1909, and immediately enrolled in the apprentice course of the Westinghouse company. Since 1911 he had been engaged in the application of electrical apparatus in steel mills.

GANO DUNN (A'91, M'94, F'12, past-president life member) president of the J. G. White Engineering Corporation, New York, N. Y., recently was elected a director of the Radio Corporation of America. A biographical sketch of Mr. Dunn appeared in the January issue of ELECTRICAL ENGINEERING, page 44.

O. W. TOWNER (A'28, M'35) has resigned as a member of the technical staff of the Bell Telephone Laboratories, Inc., New York, N. Y., to become chief radio engineer of the Louisville Times Company, Louisville, Ky. For the last ten years Mr. Towner has been supervising the erection of radio transmitting and receiving equipment throughout the United States.

L. M. NELSON (M'34) superintendent of the water and light department of the City of Hastings, Nebr., since 1933, recently resigned to become superintendent of the electricity utility system at Rochester, Minn.

Obituary

ALFRED WARNER DATER (A'23) vice-chairman of the board of directors, The Connecticut Power Company, Stamford, died February 21, 1938. Mr. Dater was born in Brooklyn, N. Y., August 23, 1872, and was graduated from Yale University in 1895 with the degree of bachelor of philosophy. His first position was with The Pennsylvania Railroad at Fort Wayne, Ind., as a machinist's helper. In 1897 he became assistant general manager of the King's County Electric Light and Power Company, Brooklyn, N. Y. During the following year that company acquired the Edison Electric Illuminating Company and Mr. Dater was elected treasurer of the combined companies, which office he held until he went to Stamford in 1903 to organize and become vice-president and treasurer of the Oven Equipment and Manufacturing Company. In 1904 he became affiliated with the Stamford Gas and Electric Company as treasurer and a director. In 1911 Mr. Dater was elected vice-president of the company, and six years later became president. When the Stamford Gas and Electric Company merged with the Connecticut Power Company in 1936, he was elected vice-chairman of the Board of Directors of The Connecticut Power Company, of which he was a director, and chairman of the Stamford Gas and Electric divisional committee. During the World War he was associated with the United States Fuel Administration and the Naval Advisory Board.

EDWIN PARTRIDGE HARDER (A'03, M'34) electrical engineer for the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., died February 14, 1938. Mr. Harder was born October 13, 1873, at Catawissa, Pa., and was graduated from Pennsylvania State College with the degree of bachelor of science in electrical engineering in 1895. Immediately following his graduation he entered the employ of the Central Electric Company, Philadelphia, Pa., later becoming foreman of construction for the Borough of Manhattan Electric Company and the New York Heat, Light, and Power Company. Following a brief affiliation with the New York Edison Company, he became superintendent of stations and inside construction for the Cataract Power and Conduit Company, Buffalo, N. Y., in 1901, remaining there until 1915, when that company was merged with the Buffalo General Electric Company, and Mr. Harder was transferred to the engineering department as an electrical engineer. A further merger in 1929 transferred Mr. Harder to the engineering department of the Buffalo, Niagara, and Eastern Power Corporation Division of the Niagara Hudson Corporation, where he was placed in immediate responsible charge of the engineering work and drafting for several 25-cycle stations. Mr. Harder was particularly active in the affairs of the Institute's Niagara Frontier Section, having held several offices including the Section chairmanship during 1934–35.

BYRON BRIGGS BRACKETT (A'97, M'13, F'35, member for life) director of educational broadcasting in charge of radio station KUSD, University of South Dakota, Vermillion, died December 12, 1937. Doctor Brackett was born August 13, 1865, at Ira, N. Y., was graduated in electrical engineering from The Johns Hopkins University in 1895, and received the degree of bachelor of philosophy from the same institution in 1897. In 1903 he was appointed professor and head of the departments of physics and electrical engineering at Clarkson College of Technology, where he remained until 1909, when he became professor of electrical engineering at South Dakota State College of Agriculture and Mechanic Arts, Brookings. In 1923 Doctor Brackett became professor and head of the department of electrical engineering of the University of South Dakota, and in 1931 was appointed director of educational broadcasting sponsored by the University. He was the first chairman of the South Dakota State Board of Engineering and Architectural Examiners to license professional engineers, and was a past-president of the South Dakota Academy of Sciences. He was a fellow of the American Association for the Advancement of Science, and a member of Sigma Xi and Phi Beta Kappa.

JOSEPH HAROLD PAGET (A'14), manager of engineering and operation of the Carolina Power and Light Company, Raleigh, N. C., died February 2, 1938. Mr. Paget was born June 29, 1888, at Boston, Mass., and attended Lowell Institute. In 1906 he entered the Lynn works of the General Electric Company, and except for one year with the Edison Electric Illuminating Company of Boston, remained with the General Electric Company until 1913. He then joined the engineering staff of the British Columbia Electric Railway Company at Vancouver as meter and relay engineer. In 1918 he was appointed plant engineer for the company, having charge of generating plants and substations. In 1919 Mr. Paget was engaged by the Mexican Light and Power Company, Mexico City as an electrical engineer. His next position was with the Great Western Power Company, which is now a part of the Pacific Gas and Electric Company, San Francisco, Calif.,

where he was assistant engineer in charge of design and construction of high-voltage automatic substations and the entire relay system. Mr. Paget became affiliated with the Carolina Power and Light Company in 1925 as superintendent of power, and was appointed manager of engineering and operation in 1935. During 1931–32 Mr. Paget served as chairman of the AIEE North Carolina Section.

JAMES F. SCHNABEL (M'37) chief engineer of the Euclid Electric and Manufacturing Company, Euclid, Ohio, died in December 1937. Mr. Schnabel was born at Petersburg, Ohio, December 19, 1881, and was graduated from Poland (Ohio) Union Seminary in 1900. In 1901 he was employed by the Economy Electric Company, Warren, Ohio, as a lamp tester and later in the same year became a draftsman for the Harris Automatic Press Company, Niles, Ohio, before taking a similar position with the Republic Iron and Steel Company, Youngstown, Ohio, in 1903. In the following year he became a draftsman for the Electric Controller and Supply Company, Cleveland, but later was transferred to the sales engineering department, and in 1911 was appointed assistant sales engineer for the company. In 1926 Mr. Schnabel transferred his affiliation to the Clark Controller Company, Cleveland, where he became engaged in research work resulting in several patents pertaining to improvements in motor control and dynamic braking of hoists. He was appointed chief engineer of the Euclid Electric and Manufacturing Company in 1933. Mr. Schnabel was active in the AIEE Cleveland Section and during 1925–26 was Section secretary.

WINFRED MORRILL (A'34) associate electrical engineer, procurement division, United States Treasury Department, Washington, D. C., died recently. Mr. Morrill was born October 22, 1888, at Sutton, Mass., and was graduated from New Hampshire State College in 1911 with the degree of bachelor of science. Following a brief affiliation with the Western Union Telegraph Company, he became an electrician for Stone and Webster in 1912. Between 1914 and 1920 Mr. Morrill held various engineering positions with the Stone and Webster company and with several manufacturing organizations. In 1922 he was made electrical foreman for the Stone and Webster company, in which position he assisted in several construction projects throughout the United States. In 1932 Mr. Morrill was transferred to the Potomac Electric Power Company, Washington, D. C., returned briefly to the employ of Stone and Webster in the same year, and in the following year entered the employ of the Virginia Electric and Power Company, Williamsburg. He was appointed to the United States Treasury Department in 1935.

JOSEPH AUKEN THALER (A'03, M'08, F'13) professor and head of the department of electrical engineering at Montana State College, Bozeman, died March 4, 1938. Professor Thaler was born September 29, 1864, at Koessen, Austria, and was graduated from the electrical engineering course of the University of Minnesota in 1900. Following his graduation he was appointed an instructor in mechanical engineering at Montana State College in 1901, going to Purdue University as an instructor in mechanics in 1902. He returned to Montana the next year to teach electrical engineering, and was appointed head of that department. Professor Thaler sponsored the installation of the AIEE Student Branch at Montana State College in 1907, and served as counselor of that Branch for more than 30 years. He was active in initiating the AIEE Montana Section and was its first chairman, holding that office for three years following the establishment of the Section in 1931. Professor Thaler was a member of Sigma XI, Tau Beta Pi, the Society for the Promotion of Engineering Education, and the Montana Society of Engineers.

HENRY WILLIAM TAYLOR (A'07) chief turbogenerator designer for the British Thomson-Houston Company, Ltd., Rugby, England, died February 1, 1938. Mr. Taylor was born in London, November 2, 1883, and received his technical education in mechanical and electrical engineering at the City of London Guild's Technical College. In 1903 he became technical assistant to Doctor S. P. Thompson (A'97, HM'14) and held that position for three years before becoming a designing engineer for the British Thomson-Houston Company. He served that organization for almost 30 years, first as a designing engineer, and later as an engineer in the turbogenerator department and as chief of that department.

BENJAMIN ROBINSON (A'20) power house operator and electrician for the Packard Motor Car Company, Detroit, Mich., died December 15, 1937. Mr. Robinson was born March 16, 1881, at Yorkshire, England, and gained his technical training by attending several trade electrical schools in England. For 16 years he was an electrician for the Scoville Manufacturing Company, Waterbury, Conn.; later he became successively assistant to the chief electrician and chief electrician for the Bristol Brass Corporation, Bristol, Conn. Mr. Robinson became affiliated with the Packard Motor Car Company in 1930.

FRANCIS ELLIOT CABOT (A'95, member for life) retired secretary and engineer of the Boston Board of Fire Underwriters, Boston, Mass., died January 7, 1938. Mr. Cabot was born in Brookline, Mass., in 1859, and was graduated from Harvard University in 1880. For a time he was a consulting electrical engineer in Boston, and served the Underwriters' Board for 43 years.

HUGH LESLEY (A'02, member for life) engineer for The Electric Storage Battery Company, Philadelphia, Pa., died in February 1938. Mr. Lesley was born in Philadelphia, August 10, 1867, and was graduated from Haverford College with the degree of bachelor of science. From 1888 until 1899 he filled various engineering positions with the Accumulator Company and the Planté Company. He became engineer in charge of the operating department of The Electric Storage Battery Company in 1899, and his association with that company was unbroken for almost 40 years.

WILLIAM GEORGE ROGERS (A'07) engineering department, The Electric Storage Battery Company, Philadelphia, Pa., died February 3, 1938. Mr. Rogers was born in Philadelphia, June 3, 1879, and attended Drexel Institute. In 1899 he entered the employ of the Philadelphia Electric Company as a draftsman. Later he was transferred to the electrical construction department, and in 1906 was placed in charge of maintenance and operation of central power plants and substations of that company. He joined the engineering staff of The Electric Storage Battery Company in 1910.

Membership

Recommended for Transfer

The board of examiners, at its meeting on March 17, 1938, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Campbell, A. B., engineer, Edison Electric Institute, New York, N. Y.
Craig, P. H., vice-president and director of laboratory, Invex Corporation; consulting engineer, Roller Smith Company, Bethlehem, Pa.
Heitzler, A. H., superintendent, electrical department, Public Service Company of Colorado, Denver.
Jones, A. L., district manager, General Electric Company, Denver, Colo.
Lewis, W. W., transmission engineer, central station department, General Electric Company, Schenectady, N. Y.
McClellan, L. N., chief electrical engineer, United States Bureau of Reclamation, Denver, Colo.

6 to Grade of Fellow

To Grade of Member

Abigail, E. W., system control engineer, Shanghai Power Company, Shanghai, China.
Ballenger, W. M., engineering department, General Electric Company, Chicago, Ill.
Brainard, D. E., section head in motor and generator engineering department, General Electric Company, Schenectady, N. Y.
Brownlee, W. R., system relay engineer, The Tennessee Electric Power Company, Chattanooga, Tenn.
Bukey, N. J., engineer, underground cable construction, Cincinnati Gas and Electric Company, Cincinnati, Ohio.
Canfield, W., engineer, Public Service Company of Oklahoma, Tulsa.
Glenn, T. G., assistant district engineer, General Electric Company, Chicago, Ill.
Hinckley, A. D., assistant to dean of faculty of engineering, and instructor in electrical engineering, Columbia University, New York, N. Y.
Howard, Otis, assistant general superintendent, Oklahoma Gas and Electric Company, Oklahoma City.
Ickis, L. S., assistant district engineer, General Electric Company, Denver, Colo.
Ide, C. E., vice-president and general manager, East Tennessee Light and Power Company, Bristol, Tenn.
Jolliffe, J. F., assistant engineer, electrical, United States Army, Corps of Engineers, Portland, Ore.
LaCausa, F. E., assistant professor of electrical engineering, postgraduate school, United States Naval Academy, Annapolis, Md.
Lindsay, R. W., chief engineer, Mountain States Telephone and Telegraph Company, Denver, Colo.

McCallum, V. E., supervising design engineer, Commonwealth Edison Company, Chicago, Ill.
Munk, Gunnar, designer, Union Carbide Company, Niagara Falls, N. Y.
Olving, B. G., development engineer, The Safety Car Heating and Lighting Company, New Haven, Conn.
Reed, O. P., district superintendent, Cheyenne Light, Fuel, and Power Company, Cheyenne, Wyo.
Smith, H. E., assistant electrical engineer, Philadelphia and Reading Coal and Iron Company, Pottsville, Pa.
Stewart, H. M., electrical engineer, Humble Oil and Refining Company, Baytown, Texas.
Warren, P. L., vice-president, Royal Electric Manufacturing Company, Chicago, Ill.

21 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before April 30, 1938, or June 30, 1938, if the applicant resides outside of the United States or Canada.

United States and Canada

Achenbach, J. C., RCA Manufacturing Company, Inc., Camden, N. J.
Amend, H. S., 1331 South Ninth Street, Lincoln, Nebr.
Anawalt, H., Puget Sound Power and Light Company, Seattle, Wash.
Andrasko, J. P., 2136 Harrison Avenue, New York, N. Y.
Angle, F. C., Allis-Chalmers Manufacturing Company, San Francisco, Calif.
Anzini, D. I. (Member), General Electric Company, San Francisco, Calif.
Archer, M. M., The Detroit Edison Company, Detroit, Mich.
Arciola, T. A., Habirshaw Cable and Wire Corporation, Yonkers, N. Y.
Argo, J. P. (Member), Memphis Power and Light Company, Memphis, Tenn.
Ashworth, F., Canada Wire and Cable Company, Ltd., Toronto, Ont.
Balters, A., New York Telephone Company, New York, N. Y.
Barnitz, R. W., The Pennsylvania Railroad, Columbia, Pa.
Barraford, J. H., Consolidated Edison Company of New York, Inc., Brooklyn, N. Y.
Barron, H. B., General Electric Company, Schenectady, N. Y.
Barry, J. F., Roberts and McInnis, Washington, D. C.
Beasley, O. A., Orlando Utilities Commission, Orlando, Fla.
Bell, R. B., King-Seeley Corporation, Ann Arbor, Mich.
Bentzel, R. J., American Gas and Electric Service Corporation, New York, N. Y.
Betz, J. F., Public Service Electric and Gas Company, Newark, N. J.
Billman, H. H., Ohio Power Company, Canton.
Birkes, R. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Blanchard, H. P., Pacific Telephone and Telegraph Company, Oakland, Calif.
Blume, A. E., 22 Maple Street, Brooklyn, N. Y.
Blumenthal, S. C., Jr., Blumenthal-Kahn Electric Company, Baltimore, Md.
Boasey, P., Tri-State College, Angola, Ind.
Bodenburg, J., 23-59 36th Street, Long Island City, N. Y.
Bollaert, R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Bond, E. M. Jr., Stewart Warner Corporation, Chicago, Ill.
Bradt, R. S., Standard Oil Company of California, San Francisco.
Brice, W. E., General Electric Company, Schenectady, N. Y.
Brignall, H. L., Canadian Pacific Railway Building, Toronto, Ont., Canada.
Brinen, P. F., Young Radiator Company, Racine, Wis.
Brooks, F. R., New York Telephone Company, New York, N. Y.
Browning, E. B., Jr. (Member), American Telephone and Telegraph Company, New York, N. Y.
Buechler, L. W., Sears Roebuck and Company, Chicago, Ill.
Burnett, W. G., Jr., General Electric Company, Pittsfield, Mass.
Burson, C. H., 6549 Palatine Avenue, Seattle, Wash.
Campbell, C. R., General Electric Company, Schenectady, N. Y.
Campbell, D. L., City of Seattle, Wash.
Campbell, H. B., United States Engineers Ft. Peck, Mont.
Carter, W. R., National Light and Power Company, Moose Jaw, Sask., Canada.
Cassell, G. J., Long Island Lighting Company, Long Island, N. Y.
Cherkesy, A. C., Electric Heating Equipment Company, Philadelphia, Pa.
Christensen, H., Bell Telephone Laboratories, Inc., New York, N. Y.
Christenson, R. W., 2517 Virginia Street, Everett, Wash.
Clark, L. W., Agricultural Adjustment Administration, Washington, D. C.
Climenson, M. G., University of Washington, Seattle, Wash.
Cobb, H. E., Allen-Bradley Company, Milwaukee, Wis.
Cogsdill, W. L., The Detroit Edison Company, Detroit, Mich.
Cohn, B. E. (Member), University of Denver, Denver, Colo.
Coone, L. A., General Electric Company, Schenectady, N. Y.
Cooper, B., Marlton, N. J.
Coxworth, V. B., Canadian General Electric Company, Ltd., Peterboro, Ont.
Crandell, C. F., Southwestern Bell Telephone Company, Kansas City, Mo.
Crouse, D. A., Ohio Power Company, Canton.
Cruikshank, M. T., Bell Telephone Company of Pennsylvania, Pittsburgh.
Cruse, A. W. (Member), Federal Communications Commission, Washington, D. C.
Dahlborg, J. E., Western Electric Company, South Kearny, N. J.
Dean, A. B., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Depp, W. A., Bell Telephone Laboratories, Inc., New York, N. Y.
Detrick, H. B., General Electric Company, Schenectady, N. Y.
Dobson, H. O., 4101/2 South Madison Street, Iowa City, Iowa.
Dumaresq, J. E., 133-03 41st Road, Flushing, N. Y.
Ecker, L. F. (Member), Illinois Iowa Power Corporation, East St. Louis, Ill.
Ehmann, G. C., Jr., 1636 Ritner Street, Philadelphia, Pa.
Ekvall, A. C., Bell Telephone Laboratories, Inc., New York, N. Y.
Endlich, R. J., Harnischfeger Corporation, Milwaukee, Wis.
Fales, F. G., 372 Granite Avenue, East Milton, Mass.
Fergg, W. F., Consolidated Edison Company of New York, Inc., New York, N. Y.
Fernald, F. W., General Electric Company, Lynn, Mass.
Folk, W., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Foote, R. P., The Pennsylvania Railroad, Columbia, Pa.
Forsetek, C. W., Forestek Plating and Manufacturing Company, Cleveland, Ohio.
Fowler, R. C., Delco Products Corporation, Dayton, Ohio.
Friedl, G., Jr. (Member), International Projector Corporation, New York, N. Y.
Frost, L. H. (Member), Electric Controller and Manufacturing Company, Cleveland, Ohio.
Frost, W. F., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Fry, H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Gaylord, A. K. (Member), Portland General Electric Company, Portland, Ore.
Geiger, L. H., Jr., 1063 Oakdale Road, Atlanta, Ga.
Gerlough, D. L., Mott-Smith Corporation, Houston, Texas.
Getz, G. G., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Gibbons, R. F., Pacific Electric Manufacturing Corporation, San Francisco, Calif.
Gifford, F. T., 94 Faxon Road, Quincy, Mass.
Gilmer, T. P. (Member), Public Service Company, Okmulgee, Okla.
Gleeson, R. G., 163 Friendly Road, Auburn, R. I.
Glogan, M. L., Allen-Bradley Company, Milwaukee, Wis.
Goeddel, L. O., Jr., 8100 Washington, Vinita Park, St. Louis County, Mo.
Gorman, W. J., Jr., General Electric Company, Schenectady, N. Y.
Gould, C. C., Carnegie-Illinois Steel Corporation, Gary, Ind.
Graef, R. P., 1135 Seton Avenue, Cincinnati, Ohio.
Gretz, C. B., New Jersey Bell Telephone Company, Newark.
Grim, C. L., 8 Beaumont Avenue, Catonsville, Md.
Grimshaw, W. B. (Member), Philtower Building, Tulsa, Okla.
Grissinger, G. G. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Gunter, D. L., General Electric Company, Schenectady, N. Y.
Guy, J. D. C., Jr., General Electric Company, Schenectady, N. Y.
Haas, O. A., Allis-Chalmers Manufacturing Company, Tulsa, Okla.
Haller, R. R., 3000 Davis Street, Dover, Ohio.
Hanke, E. W. F., Allen-Bradley Company, Milwaukee, Wis.
Hanke, W. W. (Member), Southern Electric Service Company, Charlotte, N. C.
Hannum, W. P., Public Service Company of Northern Illinois, Chicago, Ill.
Hanson, L., Consolidated Coppermines Corporation, Kimberly, Nev.
Hardaker, E. H., Wisconsin Gas and Electric Company, Racine.
Hare, S. B., 209 North 34th Street, Philadelphia, Pa.
Harris, H. H., General Electric Company, Schenectady, N. Y.
Harris, W. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Harrison, F. E., General Motors Corporation, Anderson, Ind.
Hawkins, H. G., Electric Power Equipment, Ltd., Vancouver, B. C., Canada.
Hay, T. M., Jr., United States Army, Fort Monmouth, Oceanport, N. J.
Haynes, R. L., 1921 Sewell, Lincoln, Nebr.
Hegy, J., 67 South Fifth Street, San Jose, Calif.
Heiner, S. M., Box 158, Morgan, Utah.
Herbert, C. V., Texas Electric Service Company, Handley.
Herbig, E. T., Jr., Thomas A. Edison, Inc., New York, N. Y.
Herzfeld, C. E., Westinghouse Electric and Manufacturing Company, Houston, Texas.
Hicks, W. A., Southern Bell Telephone and Telegraph Company, Atlanta, Ga.
Hill, H. H., American Gas Association, Los Angeles, Calif.
Hillebrandt, B. F., Jr., Union Electric Company of Missouri, Webster Groves.
Hockenberger, R. H., Delco Appliance Corporation, Rochester, N. Y.
Hodge, R. D., Canadian General Electric Company, Ltd., Toronto, Ont.
Holden, E. A. (Fellow), Ebasco Services, Inc., New York, N. Y.
Howard, J. T., Tennessee Valley Authority, Chattanooga, Tenn.
Hurt, G. T., Tennessee Valley Authority, Guntersville Dam, Ala.
Jacobs, P. C., Allis-Chalmers Manufacturing Company, Boston, Mass.
Jarrett, W. R., General Electric Company, Schenectady, N. Y.
Jones, D. K., 1241 South Tenth Street, Lincoln, Nebr.
Jones, R. B., Jr., Chesapeake and Potomac Telephone Company of Virginia, Richmond.
Kadison, L., Crocker-Wheeler Company, Inc., Ampere, N. J.
Kaiser, R. W., International Business Machines Corporation, Milwaukee, Wis.
Kaltenberger, L. H., 1007 Third Avenue, Longmont, Colo.
Kanable, G. M., General Electric Company, Erie, Pa.
Kasakoff, H., 4252 Parkside Avenue, Philadelphia, Pa.
Keil, H. D., Canadian Westinghouse Company, Hamilton, Ont.
Kelly, J. P., Western Electric Company, Baltimore, Md.
King, J. A., Oklahoma Gas and Electric Company, Poteau.
King, W. H., Western Electric Company, Austin, Texas.
Kingston, C. R., Westinghouse Electric and Manufacturing Company, Houston, Texas.
Kirk, C. B., Jr., Chesapeake and Potomac Telephone Company of Virginia, Blacksburg.
Kistler, L. H., Northwestern Electric Company, Portland, Ore.
Knochel, W. J., Westinghouse Lamp Division, Bloomfield, N. J.
Kozlowski, R. W., Diehl Manufacturing Company, Elizabethport, N. J.
Kuczek, R., 74 Plain Street, Taunton, Mass.
Kuhnke, W. C., 2966 South 47th Street, Milwaukee, Wis.
Lee, E. H., Lee and Company, Volga, S. D.
Lefgren, A. H., Otis Elevator Company, New York, N. Y.
Lenkerd, J. P., Works Progress Administration, Gainesville, Fla.
Libby, C. P., City of Seattle Light Department, Seattle, Wash.
Linden, C. A., General Electric Company, Pittsfield, Mass.
Link, J. H., Federal Communications Commission, Washington, D. C.
Lloyd, L. H., Idaho Power Company, American Falls.
Lockwood, H. J. (Member), Manhattan College, New York, N. Y.
Loehr, R. W., Westinghouse Electric and Manufacturing Company, Cleveland, Ohio.
Longobardi, V., Jr., Brooklyn Edison Company, Brooklyn, N. Y.
Louraie-Sulekee, A. R., 3454 North Bremen Street, Milwaukee, Wis.
Ludlow, F. W., Bethlehem Steel Company, Sparrows Point, Md.
Lukens, D. W., Ohio Power Company, Coshocton.
Lyman, R. J., Narragansett Electric Company, Edgewood, R. I.
MacLaughlin, L. H., Cincinnati and Suburban Bell Telephone Company, Cincinnati, Ohio.
Malloy, N. M., Consolidated Edison Company of New York, New York, N. Y.
Manos, E. M., 8301 South Wallace Street, Chicago, Ill.
Maple, C. A., Dayton Power and Light Company, Dayton, Ohio.
Marans, A., Bethlehem Steel Company, Sparrows Point, Md.
Marshall, R. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Martinson, L. A., General Electric Company, Schenectady, N. Y.

Massie, C. C., General Electric Company, Schenectady, N. Y.
Matthews, E. M., Jr., Western Electric Company, Kearny, N. J.
Maynard, H. M., National Youth Administration, Quoddy Village, Eastport, Me.
McCann, G. D., Jr., California Institute of Technology, Pasadena.
McClay, M. I., Utah Power and Light Company, Salt Lake City.
McDaniel, R. S., Magnolia Petroleum Company, Beaumont, Texas.
McEahern, E. J., M. McEahern Construction Company, Denver, Colo.
McKinley, E., Westington Electric and Manufacturing Company, Sharon, Pa.
McMillan, A. N., Buffalo Niagara Electric Corporation, Buffalo, N. Y.
McNall, J. W., Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.
McWilliams, J. I., Shawinigan Water and Power Company, Rapide Blanc, Que., Canada.
Merow, L. P., Consolidated Edison Company of New York Inc., New York, N. Y.
Middleton, W. L., Simplex Wire and Cable Company, Cambridge, Mass.
Miller, I. S., Kansas Gas and Electric Company, Wichita, Kans.
Minta, F. C., Humble Oil and Refining Company, Houston, Texas.
Mitchell, W. G., Singer Sewing Machine Company, Elizabethport, N. J.
Mohns, J. C., Bureau of Engineering, San Francheco, Calif.
Montgomery, J. R., Houston Lighting and Power Company, Houston, Texas.
Moore, W. H., Sperry Products, Inc., Brooklyn, N. Y.
Morris, B. C., General Electric Company, Philadelphia, Pa.
Morrison, P., Carnegie-Illinois Steel Corporation, Chicago, Ill.
Munson, H. J., 19 Bradley Road, Tacoma, Wash.
Murphy, L. T., Memphis Light and Water Division, Memphis, Tenn.
Nichols, R. M., Tranco Development Corporation, Los Angeles, Calif.
Nielsen, G. E., Federal Communications Commission, Washington, D. C.
Norton, R. B. (Member), Kerite Insulated Wire and Cable Company, Seymour, Conn.
Nunan, K., 440 South Grand Oaks Avenue, Pasadena, Calif.
Oakley, A. W., Jr., 610 West High Street, Terrell, Texas.
O'Connor, T. J., General Electric Company, West Lynn, Mass.
Odessey, P. H., Heyer Products Company, Inc., Belleville, N. J.
O'Leary, J. T., Bell Telephone Laboratories, Inc., New York, N. Y.
Olsen, J. W., Owens-Illinois Glass Company, Clarion, Pa.
O'Neil, F. S., American Telephone and Telegraph Company, New York, N. Y.
Orem, S. R., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Owens, O. G., General Electric Company, Pittsfield, Mass.
Owings, C. B., General Electric Company, Pittsfield, Mass.
Palmer, H. C., General Railway Signal Company, Rochester, N. Y.
Peckham, M. A., General Electric Company, Schenectady, N. Y.
Peery, W. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Peterson, W. L., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Phares, J. A., Interstate Electric Company, Fort Smith, Ark.
Pilger, C. F., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Plummer, W. B., RCA Communications, Inc., Tuckerton, N. J.
Pope, E. B., General Electric Company, Schenectady, N. Y.
Porter, R. W., General Electric Company, Schenectady, N. Y.
Porter, T. R., Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.
Powell, A. H., General Electric Company, Philadelphia, Pa.
Pratt, G. B., 4303 Tyler Avenue, Detroit, Mich.
Price, W., Price Engineering Service, Brookline, Mass.
Pugh, H. F., 2375 East Evans, Denver, Colo.
Pyle, K. N., Ingersoll-Rand Company, Phillipsburg, N. J.
Raub, J. M., Southwestern Light and Power Company, Lawton, Okla.
Rechif, F. A., Continental Oil Company, Ponca City, Okla.
Rehm, T. C., Bell Telephone Laboratories, Inc., New York, N. Y.
Ridley, C. R., The Macnick Company, Tulsa, Okla.
Riechers, T. W., Northern Indiana Public Service Company, Hammond, Ind.
Rister, C. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Rittenhouse, S. A., Consolidated Gas Electric Light and Power Company, Baltimore, Md.
Roberts, J. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Robertson, G. M., General Electric Company, Pittsfield, Mass.
Rochm, P. R., New Orleans Public Service, Inc., New Orleans, La.
Rohweder, J. H. (Member), Citizens Light and Power Company, Erie, Mich.
Romanko, N. F., Raritan Copper Works, Perth Amboy, N. J.
Ruwell, R. G., Bell Telephone Company of Pennsylvania, Philadelphia, Pa.
Ryan, J. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Saalbach, H. K., United States Patent Office, Washington, D. C.
Sampson, H. C., Nebraska Power Company, Omaha, Nebr.
Sampson, L. H., The Detroit Edison Company, Detroit, Mich.
Sander, H. J., Bell Telephone Company of Pennsylvania, Pittsburgh.
Sanderford, R. B., Tennessee Valley Authority, Memphis, Tenn.
Saunders, H. M., Western Union Telegraph Company, New York, N. Y.
Saylor, W. R., General Electric Company, Philadelphia, Pa.
Scarborough, H. V., Jr., General Electric Company, Schenectady, N. Y.
Schmalbach, S., Mooradian High Frequency Laboratories, Bogota, N. J.
Schmand, D. A., 1416 Center Street, Little Rock, Ark.
Schmidt, L. B., Denver Rio Grande Western Railroad Company, Grand Junction, Colo.
Schulman, I., Bethlehem Construction and Utilities Company, New York, N. Y.
Schunker, L. P., Jr., General Electric Company, Schenectady, N. Y.
Schumann, L. I., 3425 Kossuth Avenue, New York, N. Y.
Schwartz, D. A., 1701 South Gayoso Street, New Orleans, La.
Semrad, C. J., General Electric Company, Schenectady, N. Y.
Settle, C., 2003 Columbia Road, N. W., Washington, D. C.
Sharkey, E. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Sheen, R. G., Public Service Company of Colorado, Denver.
Shideler, J. J., Western Electric Company, Des Moines, Iowa.
Shorey, L. F., University of Vermont, Burlington.
Shumaker, L. L., Delco Products Corporation, Dayton, Ohio.
Shutts, R. C., General Electric Company, Philadelphia, Pa.
Simpson, R. L., General Electric Company, Schenectady, N. Y.
Slepian, A., Wheeler Insulated Wire Company, Bridgeport, Conn.
Sloan, C. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Smith, D. W., American Rolling Mill Company, Butler, Pa.
Smith, E. S., Eclipse Aviation Corporation, East Orange, N. J.
Smith, V. L., Civilian Conservation Corps, Camp S-80, Masten, Pa.
Spence, B. G., Oklahoma Gas and Electric Company, Enid, Okla.
Staley, K. (Member), General Electric Company, New York, N. Y.
Steen, E. M., Commonwealth Edison Company, Chicago, Ill.
Stefanetti, Henry J., Pacific Gas and Electric Company, Red Bluff, Calif.
Stewart, H. J., General Electric Company, York, Pa.
Stewart, V. N., General Electric Company, Schenectady, N. Y.
Stillwell, R. M., Union Electric Company of Illinois, Alton.
Stipe, J. L., General Electric Company, Schenectady, N. Y.
Storck, N. C., Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Strandrud, H. T., United States Bureau of Reclamation, Ephrata, Washington.
Thomas, M. E., Phillips Petroleum Company, Bartlesville, Okla.
Tibbets, W. S., Bethlehem Steel Company, Sparrows Point, Md.
Tipple, H. L., Canadian National Carbon Company, Ltd., Toronto, Ont.
Touton, L. L., Jr., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Townsend, M. A., General Electric Vapor Lamp Company, Hoboken, N. J.
Treseder, R. S., Mountain States Telephone and Telegraph Company, Salt Lake City, Utah.
van de Kamp, W., Westinghouse Electric and Manufacturing Company, Emeryville, Calif.
Van Lund, J. A., Jr., General Electric Company, Schenectady, N. Y.
Vaughan, H. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Vaughn, H. W., Memphis Light and Water Division, Memphis, Tenn.
Waddington, L. A., Mountain States Telephone and Telegraph Company, Denver, Colo.
Wallace, W. E., General Electric Company, Schenectady, N. Y.
Watson, F. L., Keystone Telephone Company of Philadelphia, Philadelphia, Pa.
Wearly, W. L., Joy Manufacturing Company, Franklin, Pa.
Weber, V. D., Oklahoma Gas and Electric Company, Enid.
Weiman, D. N., 393 East 18th Street, Brooklyn, N. Y.
Welch, D. R., Sinclair Refining Company, Tulsa, Okla.
Weller, R. N., Consolidated Edison Company of New York, Inc., New York, N. Y.
Wenzel, F. E., Louis Allis Company, Milwaukee, Wis.
Wiederkehr, K. P., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Wilcox, S. C., 10515 Wilbur Avenue, Cleveland, Ohio.
Wiley, D. G., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Wilson, N. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Wilcox, T. N., General Electric Company, Schenectady, N. Y.
Willeman, A. H., Indiana and Michigan Electric Company, Fort Wayne, Ind.
Willey, F. G., General Electric Company, Erie, Pa.
Williams, R. E., Jr., General Electric Company, Schenectady, N. Y.
Williamson, T. D., Jr., Petroleum Engineering and Equipment Company, Tulsa, Okla.
Wood, D. O., Hygrade-Sylvania Corporation, Salem, Mass.
Wood, E. I., Westinghouse Electric and Manufacturing Company, Houston, Texas.
Wright, S. K., New England Power Company, Readsboro, Vt.
Young, C. M., General Electric Company, Schenectady, N. Y.
Young, J. L. H., Southern Bell Telephone and Telegraph Company, New Orleans, La.
Zima, L. C., 1078 Appleton Avenue, New York, N. Y.

Total, United States and Canada—803

Elsewhere

Clinchard, W. C., Jr., Box 1545, San Juan, Porto Rico.
Gittoes, C. S. (Member), Ducon Condenser Pty., Ltd., Waterloo, Sydney, Australia.
Havinga, T. H., Box 13, Christiana, Transvaal, South Africa.
Kuai, S. C., Lane 45, House No. 6, Great Western Road, Shanghai, China.
Miller, A. K., Panama Canal, Balboa Heights, Canal Zone.
Moorthy, C. V. D., Osmania Central Technical Institute, Hyderabad, Deccan, India.
Wills, E. H., Howard Smith, Ltd., Townsville, North Queensland, Australia.

Total elsewhere—7

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

RADIO AMATEUR'S HANDBOOK. 1938. Edited by the American Radio Relay League. 15th edition. West Hartford, Conn., 446 pages, illustrations, 10 by 7 inches, paper, $1.00. Covers comprehensively the amateur short-wave field. Describes the fundamental principles and the design, construction and operation, of transmitting and receiving apparatus.

INDIAN WATER POWER PLANTS, a companion volume to Hydro-Electric Installations of India. By Shiv Narayan. Published by Brij Narayan, Poona Electric Supply Company, Ltd., Ganeshkhind Road, Poona 5, India, 1937. 172 pages, illustrated, 10 by 7 inches, cloth, Rs. 5/-. Descriptive information concerning hydro-electric plants and projects of the past decade in India and Burma, geographically divided, showing the progress and present position of Indian hydro-electric power.

LIST OF RETIREMENT UNITS for ELECTRIC UTILITIES, prepared by Committee on Statistics and Accounts of Public Utility Companies of National Association of Railroad and Utilities Commissioners. New York, State Law Reporting Company, 1937. 21 pages, mimeographed, 11 by 9 inches, paper, $0.65. A supplement to the Uniform System of Accounts for Electric Utilities. Its purpose is to create greater uniformity in accounting for replacements of property and for depreciation by providing more accurate and uniform distinction between replacements which should be classed as property additions and those to be classed as maintenance.

Transactions

Papers and Discussions Comprising Pages 171–226 of the 1938 Volume

Sharp Cutoff in Vacuum Tubes, With Applications to the Slide-Back Voltmeter

By C. B. AIKEN, MEMBER AIEE L. C. BIRDSALL, ENROLLED STUDENT AIEE

Synopsis: That the current-voltage characteristics of vacuum tubes obey an exponential law near cutoff is pointed out. The larger the coefficient k appearing in the exponent, the steeper will be the current-voltage curve, and the better suited the tube will be for use in a slide-back voltmeter. The problem of obtaining high values of k is considered, and a simple theory of rectification by an exponential conductor is given. The error inherent in slide-back voltmeters of the ordinary type is discussed, and a correction factor applicable to sine waves is derived. The circuit of a slide-back vacuum-tube voltmeter which includes means for measuring the k of the tube is shown.

WHEN a high-vacuum tube is used as a small-voltage rectifier, or as a threshold indicator, it is usually desirable that the current-voltage curve have as abrupt a cutoff as possible. In many cases a sharp angle at the foot of the characteristic would be valuable, but, since this cannot be realized in a high-vacuum device, we must be content with obtaining a rapid rise in current as the control voltage is increased in the positive direction.

Despite the fact that many very satisfactory forms of direct-reading vacuum-tube voltmeters have been developed during the last few years, the slide-back[1,2] type is still an extremely useful instrument. In this type, a triode, or multielectrode tube, is biased almost to cutoff, and the reading of a d-c voltmeter which indicates the bias is noted. The signal to be measured is then applied to the grid in series with the bias voltage, and the bias is increased until the cutoff point is again reached. The difference in the two readings of the d-c voltmeter equals the peak value of the alternating voltage under measurement. The simplicity of this instrument, together with the fact that an accurate d-c voltmeter may be used to measure a-c peak voltages, makes it the most suitable device for many applications. Moreover, it is easily built and manipulated by men who have had no experience with vacuum tube circuits.

However, the slide-back voltmeter will give accurate results only if the voltage under measurement is reasonably large. When taking a reading with it, we must allow the peak of the impressed alternating voltage to swing past cutoff by an amount sufficient to produce a detectable current in the plate circuit of the tube. Just how much past cutoff this is is not ordinarily known, and consequently an uncertainty is introduced into the reading. If the potential under measurement is only a few volts, a considerable error may result.

In this paper, a study is made of the conditions which lead to the most rapid rise of the plate current versus grid voltage characteristic of a vacuum tube, and the results are applied to the operation of a slide-back voltmeter. The error involved in the measurement of small voltages is discussed, and a correction factor is derived which makes it possible to obtain accurate measurements of sinusoidal waves having peak values of as little as half a volt.

Form of Current-Voltage Curves

At very low currents, the theoretical equation of a diode is given by[3]

$$I = I_s e^{\frac{-eV}{KT}} \tag{1}$$

in which V is the voltage between the electrodes, I_s is the saturation current, T is the absolute temperature, e is the charge of an electron $= -1.59 \times 10^{-19}$ coulombs, and K is Boltzmann's constant $= 1.37 \times 10^{-23}$ joules per degree. Actually, the grid current-grid voltage characteristic of commercial high-vacuum tubes is found to be exponential in form over a limited range.

Let the coefficient of V be represented by k. Then, putting in the numerical values quoted, there results

$$k = \frac{-e}{KT} = \frac{11{,}600}{T} \tag{2}$$

Then

$$I = I_s e^{kV} \tag{3}$$

We may evaluate k experimentally at any given temperature. Its value for the grid voltage-grid current curve of average receiving tubes lies between 5 and 11, and the exponential law holds over a range of about 0.6 volts.

The quantity I_s is of no great interest to us here, since the factor which multiplies the exponential term in the current equation can be varied at will by adjusting the bias

Paper number 37-91, recommended by the AIEE joint subcommittee on electronics and presented at the AIEE winter convention, New York, N. Y., January 24-28, 1938. Manuscript submitted July 26, 1937; made available for preprinting January 3, 1938.

C. B. AIKEN is associate professor of electrical engineering in charge of communication at Purdue University, Lafayette, Ind., L. C. BIRDSALL, a former student at the university, is an engineer with the Automatic Electric Company, Chicago, Ill.

1. For all numbered references, see list at end of paper.

voltage. Thus, if we apply a bias $-V_s$ and a variable voltage v, (3) gives

$$I = I_s e^{k(V_b + v)} = G e^{kv} \tag{4}$$

G being a new constant. Evidently, it is k, and not I_s, which, from a circuit-theory standpoint, is an important parameter of a given tube.

In the case of a multielectrode tube, there is, of course, no necessary relation between the plate current-grid voltage characteristic and the curve defined by (1), since the degree of control which the grid exercises upon the electron stream is dependent upon a number of different factors. However, it is not unreasonable to suppose that, with an efficient grid structure allowing very little leakage of lines of force around it, the equation for low currents might be similar to (1). The most efficient grid structure encountered in ordinary tubes is that of the screen in a tetrode or pentode. We may expect that when the screen is used as the control element, a more rapid variation of plate current with grid voltage will be obtained near cutoff than when the ordinary grid is used. Whether or not the current-voltage curve is exponential is best determined by experiment.

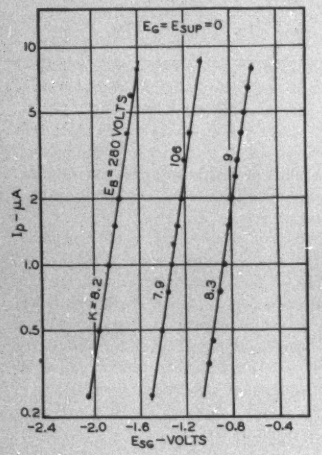


Figure 1. Curves of plate current versus screen-grid voltage for a type 77 tube

It is to be noted that plate voltage has only a small effect on the slope of these curves

Figure 1 shows semilogarithmic plots which were taken of the plate current-screen voltage characteristics of a type 77 vacuum tube, the suppressor and control grid being connected to the cathode. The three curves are for widely different values of plate voltage, and it is to be seen that an exponential law is obeyed in all three cases. Furthermore, the slope of all the curves is practically the same.

Figure 2 shows $I_p - E_{sg}$ characteristics of two other type 77 tubes and one 6D6. The former are exponential up to about ten microamperes, and the latter to about five microamperes.

Strictly speaking, an exponential characteristic has no cutoff point, since the curve approaches the voltage axis asymptotically. In practice, however, the plate current is regarded as being cut off when it is reduced to so small a value that it can no longer be read on the plate-circuit microammeter. As the control element is made less negative, the meter will finally show a reading, which will then increase, as the control voltage is further changed, with a rapidity that is determined by the constant k of (3). The larger k is, the more abrupt is the rise of current, and hence the more satisfactory the tube will be for use in a slide-back voltmeter or similar device.

The values of k determined graphically from the slopes of the curves of figure 1 are marked on them, and it will be seen that k is not greatly dependent upon the plate voltage. With such steep slopes, the graphical determination may easily be in error by several units in the second digit, and consequently we may say that k is roughly constant with respect to plate voltage.

Effect of Operating Conditions on k

The curves of figure 1 have shown the small effect of changes in plate voltage on k. Figure 3 shows a group of curves, taken on another type 77 tube, in which the suppressor voltage is the parameter. Here again an exponential law is obeyed over the range which was measured. The graphically determined values of k are again shown on these curves, and it is evident that suppressor voltage has no marked effect upon this quantity, although positive voltages tend to reduce it somewhat.

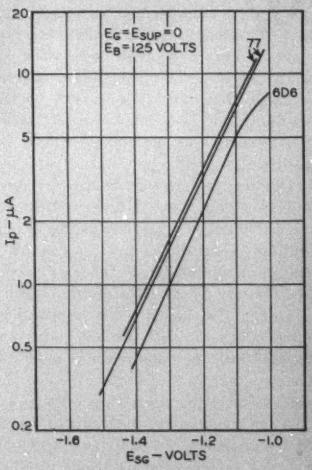


Figure 2. Curves of plate current versus screen-grid voltage for two different model 77 tubes and a 6D6

Having established the fact that the current-voltage characteristics with which we are dealing are substantially exponential at low currents, a better method of measuring the quantity k was devised. This was desirable, since the

graphical determination is both slow and inaccurate. The new method involved adjusting the voltage of the control element until the plate current read one microampere, and then applying a sine-wave alternating voltage from an adjustable potential divider and varying its magnitude until the plate current was increased to ex-

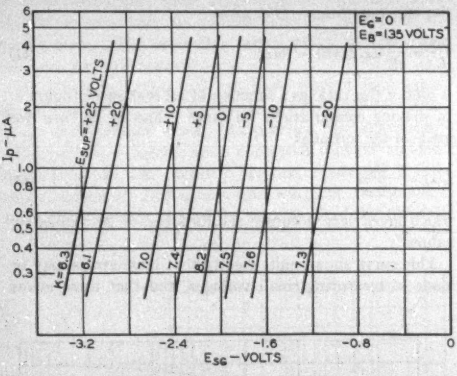


Figure 3. Effect of suppressor grid voltage on the plate current versus screen-grid voltage curves. Large positive voltages tend to reduce the slope

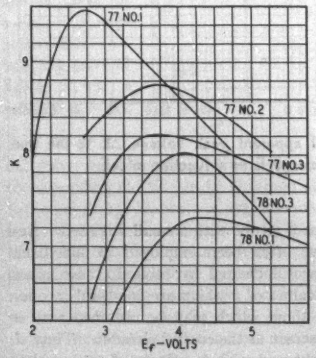


Figure 4. Variation of k with heater voltage for five different screen-grid tubes

actly two microamperes. If E_a is the peak value of the applied alternating voltage, k is given by

$$k = 1.81/E_a \qquad (5)$$

The justification for this relation will be given later on.

The effect of heater voltage on the k of these same tubes was next studied, with results as shown in figure 4 for five different tubes. As the filament temperature is reduced, k increases, and this is as predicted by (2). However, if the filament temperature is dropped far enough, k must of course decrease, and would become zero when the emission stopped altogether.

If k is calculated from (2) for 1,120 degrees absolute, which is a typical operating temperature for oxide-coated cathodes,[2] a value of 10.37 is obtained. This is a little greater than the largest observed value of k, even though the latter occurred at a temperature below that of normal operation.

The values of k calculated from (2) for thoriated (2,000 degrees) and pure tungsten (2,550 degrees) cathodes are 5.80 and 4.55, respectively. Evidently oxide-cathode tubes are to be preferred for use in a slide-back voltmeter.

It was found that the voltage of number one grid had only a small effect on k over the range of +1.0 to −0.2 volts. However, negative biases of half a volt or more caused a large reduction in this parameter.

Table I

Type of tube	k
79—number 1	3.4
79—number 2	3.6
76—number 1	2.6
76—number 2	1.9
77*—number 1	2.7

* Number 1 grid and screen grid connected together as control element.

Table II

Type of tube	k
24—number 1	8.1
24—number 3	7.7
35—number 1	4.6
57—number 1	7.6
58—number 1	8.6

Values of k for Other Electrode Arrangements and for Other Tubes

As might be expected, a screen-grid tube showed a smaller value of k when the number one grid was used as the control element. This was true even with type 77 tubes, which cut off very much more quickly than do those having variable-mu structures. Thus, values of from 2.0 to 2.8 were found for 77's used in the normal manner.

A number of other tubes were also measured, with the results shown in table I. In all cases the plate voltage was 135 volts and the bias of the control element was adjusted to give an initial current of one microampere. Table II shows the values of k for several screen grid tubes of older types. The screen was used as the control element in each case, and the number one grid and suppressor, if any, were connected to the cathode. It is evident from these tables that tubes used with screen control give very much better values of k than do triodes, or pentodes used in the normal manner.

From the data which have been presented, it is clear that the operating voltages, with the exception of the heater voltage, of a pentode used with screen-grid control do not greatly affect the value of k. If the heater voltage is kept strictly constant, k is reasonably constant. Meas-

urements taken at four different times during a period of a week, on three different type 77 tubes, showed a maximum variation of k with time, for any tube, of less than four per cent.

Rectification by an Exponential Conductor

If a sinusoidal voltage is applied to a device whose current-voltage curve is defined by (4), we have

$$I = Ge^{-kE\cos\omega t} \tag{6}$$

The d-c component of this expression can be shown to be[4]

$$I = GI_0(kE) \tag{7}$$

in which $I_0(kE) = J_0(\sqrt{-1}\,kE)$. I_0 is the zero-order Bessel function of a pure imaginary argument. Values of I_0 are to be found tabulated on pages 277–82 of "Tables of Functions," by Jahnke and Emde, second edition, 1933.

As has already been explained, G can be adjusted to any desired value by means of an appropriate bias voltage. When the impressed alternating voltage is zero, $I_0(kE) = I_0(0) =$ unity. Suppose that the bias is so adjusted that $G = 1$ microampere when there is no impressed voltage wave. If, then, an alternating voltage is placed on the grid, the current in microamperes will be equal to $I_0(kE)$. If this impressed wave is adjusted to a value E_a, such that the d-c plate current is two microamperes, we have

$$I_0(kE_a) = 2 \tag{8}$$

From the tables we find that $I_0(x) = 2$ when $x = 1.81$. Hence, (5) follows immediately. It is to be remembered that E_a is the peak value of the impressed sinusoidal wave of voltage which will change the d-c plate current from an initial value of one microampere to twice that value.

When a sinusoidal voltage is to be measured with a slide-back voltmeter, the bias is first adjusted, in the absence of impressed voltage, until the plate current has a low, but readable value. If the grid bias corresponding to this condition is E_1, we have

$$I_1 = Ge^{-kE_1} \tag{9}$$

The alternating voltage is then applied and the bias readjusted until the original current reading is restored. Then

$$I_1 = Ge^{-kE_2}I_0(kE) \tag{10}$$

Table III

Peak Alternating Current	f(kE)	ΔE Calculated	E Measured
0.565	0.631	0.356	0.35
0.848	0.724	0.613	0.60
1.132	0.776	0.88	0.87
1.414	0.813	1.15	1.14
2.83	0.890	2.52	2.51
4.24	0.920	3.90	3.90
5.66	0.938	5.31	5.28
7.07	0.950	6.72	6.71
8.49	0.957	8.13	8.11
9.90	0.966	9.56	9.51
14.14	0.970	13.72	13.77
16.98	0.973	16.53	16.53
21.21	0.980	20.8	20.8

Let this difference between the two bias voltages $(E_2 - E_1)$ be ΔE. Then, equating (9) and (10) we get

$$e^{k\Delta E} = I_0(kE) \tag{11}$$

In the ordinary use of this type of voltmeter, it is assumed that $\Delta E = E$. Actually, this is not the case, and, in order to find the magnitude of the error, let us take the ratio of the two quantities. (11) gives

$$\frac{\Delta E}{E} = \frac{1}{kE}\log_e I_0(kE) = f(kE) \tag{12}$$

A plot of this ratio as a function of kE is shown in figure 5. In making computations for large values of kE, use was made of the formula[5]

$$I_0(x) = \frac{e^x}{\sqrt{2\pi x}} \tag{13}$$

which gives very accurate results for $x = 20$ and larger values.

This curve shows quite clearly that large errors may be made in measuring small voltages, and that these errors

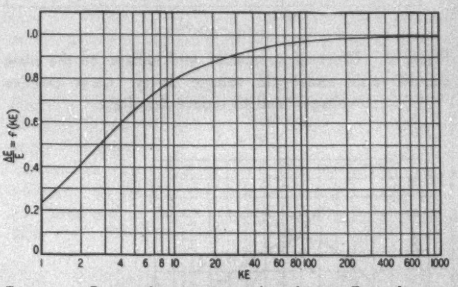


Figure 5. Ratio of apparent peak voltage ΔE to the true peak voltage E as a function of kE

are the more serious if a tube with a small k is used. Actually, triodes have often been employed in slide-back voltmeters, and, as is indicated by table I, these tubes are likely to have values of k which are one-third to one-fourth as great as those which may be obtained with a pentode, using the screen as the control element. Thus, if we have a k of eight and a peak voltage of seven volts, the error in measurement will be five per cent (corresponding to $kE = 56$), whereas if k is only two, the error for the same applied peak voltage will be about 16 per cent.

A check of the validity of (12) is given by table III. In taking data for this table, an a-c source was adjusted to 15.0 volts root-mean-square by means of an accurate voltmeter, and a potential divider was used to obtain the smaller voltages. The value of $f(kE)$ corresponding to each peak voltage was determined from the curve of figure 5, and this, multiplied by the peak voltage, gives the value of ΔE which should result. The measured and calculated values are shown in table III.

The per cent correction is small for the higher voltages,

but is quite large for peak values of a few volts or less. For the lowest voltage recorded, the error which would be made by omitting the correction factor would be 23 per cent of the impressed voltage. There is no reason why still smaller voltages could not be measured if sufficiently sensitive meters were used. When a slide-back voltmeter has been set up to measure large voltages, it often turns out that small ones must also be dealt with, and it is usually inconvenient to provide another voltmeter to handle them. The correction factor which has been developed makes this unnecessary.

In calculating table III, we have worked backwards from a known alternating voltage, and obtained the value of ΔE which should result. In practice, the alternating voltage will be unknown, and a correction must be applied to the observed ΔE. When k has been measured, it is a simple matter to plot a curve showing the relation between the observed ΔE and the peak value of the sinusoidal wave which is being measured, since the value of E corresponding to ΔE can be obtained directly from figure 5 as soon as k is known. A typical curve of E versus ΔE for $k = 8.2$ is shown in figure 6. Of course, this correction is accurate only if the voltage being measured is reasonably sinusoidal. It cannot be applied to nonsinusoidal waves, nor can a simple correction factor for measuring such waves be derived, for the ratio of ΔE to the true peak voltage would depend upon both the amplitudes and the phases of the harmonics, and these are usually unknown.

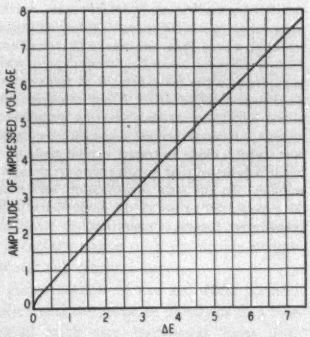


Figure 6. Calibration curve of a slide-back voltmeter derived from the curve of figure 5 for a value of k = 8.2

Circuit of the Slide-Back Voltmeter

Figure 7 shows the circuit of a slide-back voltmeter which is arranged for making measurements of k, as well as of unknown voltages. In order to measure k, the switch S is thrown into position 2, and resistance R_1 is adjusted until the voltage E_0 is equal to some reference value, say 50 volts peak. This value is determined by measurement with the slide-back voltmeter in the following manner. With the 60-cycle supply cut off, potentiometer P_3 is adjusted until the plate-current meter reads some small value, such as one or two microamperes, and the reading of voltmeter E_c is noted. P_3 is then increased by exactly 50 volts, the 60-cycle supply is switched on, and R_1 is adjusted until the plate current again reads the same as before. The voltage across R_2 and P_2 will then be 50 volts peak, except for the error inherent in a slide-back voltmeter, which we have been discussing in this paper. However, if a type-77 pentode tube is used in the voltmeter, it will have a value of k not far from 8, and hence kE will be about 400, and reference to figure 5 shows that the error will not be greater than one per cent. This can be eliminated if we use an increment in screen grid bias of 49.5 volts instead of 50 volts. Having adjusted the voltage across R_2 and P_2 to the proper value, the switch S is next thrown into position 3, and P_2 is adjusted until the plate current reads twice the no-signal value. Very small currents should, of course, be used. The value of k will be inversely proportional to the voltage across P_2, as shown by (5), and consequently the dial of P_2 may be calibrated to read k directly.

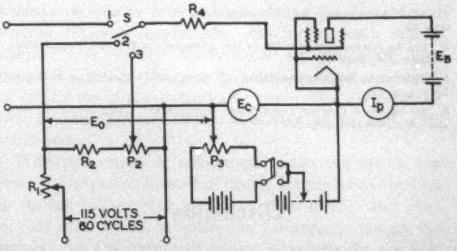


Figure 7. Circuit of a slide-back voltmeter with arrangements for measuring the value of k

When k has been measured, a curve such as that shown in figure 6 can be plotted with the help of figure 5, thereby calibrating the instrument. An unknown voltage is then measured by throwing the switch to position 1, short-circuiting the input terminals, and adjusting P_3 until the plate current is about one microampere. E_c is then increased to a value larger than the peak voltage to be measured, and the latter is applied to the input terminals. It is important to make E_c large enough in order to avoid damage to the plate-current meter. Next, P_3 is adjusted until the plate current is restored to its original value, and the increment in E_c is noted. This increment gives the peak of the voltage under measurement, by reference to the calibration curve.

R_4 is a high resistance of the order of 0.25 to 0.5 megohm, which will prevent the grid from going positive if the input voltage is accidentally allowed to exceed the bias voltage by any large amount. This furnishes some protection to the plate-circuit meter, but reasonable care will still be required to prevent damage to a sensitive instrument.

A plate voltage of 150 to 170 volts is satisfactory with type-77 tubes. If lower voltages are used, there is danger that the tube will draw grid current when a reading of one microampere plate-current is obtained, and this would

lower the input impedance of the device. Moreover, if R_4 is in circuit, this would also introduce large errors in the measurements. If higher plate voltages are employed the maximum plate current which can occur during overload is increased, thereby adding unnecessarily to the ease with which the plate meter may be injured.

This voltmeter is simple and accurate, and greatly extends the range of usefulness of the slide-back type of instrument.

References

1. High-Frequency Measurements, August Hund. McGraw-Hill, section 67.

2. Measurements in Radio Engineering, F. E. Terman. McGraw-Hill, page 28.

3. See, for instance, Phenomena in High-Frequency Systems, August Hund. McGraw-Hill, page 7.

4. Theory of Bessel Functions, G. N. Watson. Cambridge University Press, page 22.

5. See Electric Circuit Theory and Operational Calculus, J. R. Carson. McGraw-Hill, page 129.

Discussion

C. F. Harding (Purdue University, Lafayette, Ind.): The unique method, described in this paper, in making possible the measurement of crest potentials with the slide-back voltmeter principle not only marks another important step in the varied application of standard electronic tubes but also provides a simple and fairly accurate device for determining these rather evasive values. It is readily used, in connection with a resistance or capacitance potentiometer, for determining the important crest values of sustained wave forms in the extra-high-potential laboratory.

However, this combination with the slide-back voltmeter, requiring as it does two readings for every potential determination, is not applicable to steep-front surges nor to nonrepetitive wave shapes. It is hoped that, as the result of this study, the electronic tube, which seems to be well adapted to such control, may be soon adapted to the measurement of the individual crest values of surges of the order of one microsecond duration or less with a single reading and that ultimately such may be reduced down to cgs units to provide the much-desired primary standards for extra-high-potential measurements. Unfortunately, in spite of the long and careful experimentation and consideration of the committee on high-voltage standards, nothing better than the sphere gap has been developed for surge potential measurement. This gap has many disadvantages and, furthermore, is not a primary standard. It is hoped that this paper may act as a possible solution and a valuable progress report looking toward that important selection of such a primary standard.

C. B. Aiken and L. C. Birdsall: As Doctor Harding points out, the slide-back voltmeter is not, of course, applicable to nonrepetitive wave forms, nor is the correction derived in this paper applicable to repeated waves that are markedly nonsinusoidal. However, the diode rectifier can undoubtedly be adapted, with the help of auxiliary apparatus, to the measurement of transient voltages in which the maximum value of dE/dt is not too great, the limit being determined largely by irreducible stray capacitances in the measuring circuits. It would require a special investigation to determine just how useful a diode voltmeter can be made for surge measurements, but it is believed that an advance over present equipment would be possible. In any such investigation, advantage could be taken of the exponential nature of the diode characteristic in working out a quantitative theory of operation.

Interpretation of Oscillograms of Arc-Welding Generators in Terms of Welding Performance

By K. L. HANSEN
FELLOW AIEE

IT HAS long been recognized that the transient performance of an arc-welding generator greatly exceeds its static performance in importance. By transient performance is meant the behavior of the machine during the period of readjustment after a disturbance has taken place in the external circuit. Unlike most generators, an arc-welding generator supplies energy to a load in which conditions are continually changing, and the importance of the machine's ability to respond quickly to these rapid variations is obvious.

In the literature on arc-welding generators can be found many discussions on the static, or steady-state volt-ampere curve. The static volt-ampere curve is obtained by taking readings of voltage and current when the external load resistance is varied in suitable steps from infinite value on open circuit to approximately zero value on short circuit. Sufficient time is taken on each step of resistance to allow the current and voltage to settle to steady values before readings are taken; in other words, it is a characteristic volt-ampere curve for a slowly varying resistance only. Many arguments have been advanced for a certain shape or a particular degree of steepness of the static volt-ampere curve.

The volt-ampere characteristic of the arc when plotted with volts as ordinates and amperes as abscissas is a line approximately parallel with the horizontal base line. From this it is inferred that a steep volt-ampere characteristic of the welding system, which crosses the arc characteristic in such a manner as to make a large angle at the intersection, will be conducive to arc stability.

However, with the possible exception of the constant potential welding generator with negligible inductance in the arc circuit, the relation between voltage and current indicated by the static volt-ampere curve never prevails under actual welding conditions. For that reason it is not the steepness of the static volt-ampere curve which is the principal factor in determining arc stability, but the steepness of the transient or dynamic volt-ampere curves. Yet the writer has never observed any discussion on the shape or steepness of the much more important transient or dynamic volt-ampere curves.

Figure 1 shows an oscillogram of the arc voltage and current which may be considered typical, the generator and the covered electrode used both being standard commercial articles. An automatic head was employed to feed the electrode. The voltage drops to zero as the drops of molten metal short-circuit the arc at more or less regular intervals. Whenever the drops short-circuit the arc the familiar momentary rise of current can be observed. However, even between drops the current and voltage fluctuate continually and never reach steady values. The voltage fluctuations are especially pronounced. Unlike the steady resistance load employed in taking the static volt-ampere curve, the resistance of the welding arc constantly undergoes rapid and wide variations.

When the metal is transferred across the arc in the form of fine pellets instead of drops, the periodic reduction in the arc voltage may not be so pronounced. But even in that case there is a noticeable variation in the arc resistance, as the stream of pellets is apparently not uniform but takes place in gushes. It has been generally assumed that with a coated weld rod the metal is transferred in a more finely divided state than when a bare rod is used.

However, the degree of comminution of the molten metal appears to depend on the magnitude of the current rather than the coating. When using a current which is large for the size of the rod the fluctuations of voltage and current are greatly minimized with either a coated or a bare weld rod. With the current densities usually employed, the voltage fluctuations are substantially as shown in figure 1 and they may be considered typical.

Figure 1. Oscillogram of arc current and voltage; approximately 200 amperes, 30 volts

The current fluctuations attendant upon the short circuiting of the arc have been subject to considerable discussion. Some maintain that they are detrimental in that they increase spatter and lower the deposition efficiency, and may even cause porosity. Others claim that they improve the penetration and are therefore de-

Paper number 37-142, recommended by the AIEE committee on electric welding and presented at the AIEE winter convention, New York, N. Y., January 24-28, 1938. Manuscript submitted October 30, 1937; made available for preprinting January 3, 1938.

K. L. HANSEN is a consulting engineer for the Harnischfeger Corporation, Milwaukee, Wis.

1. For all numbered references, see list at end of paper.

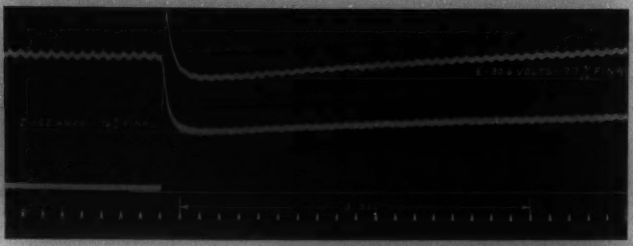


Figure 2. Oscillogram of current and voltage on short to load test on 200-ampere welding generator set at 200 amperes, 40 volts

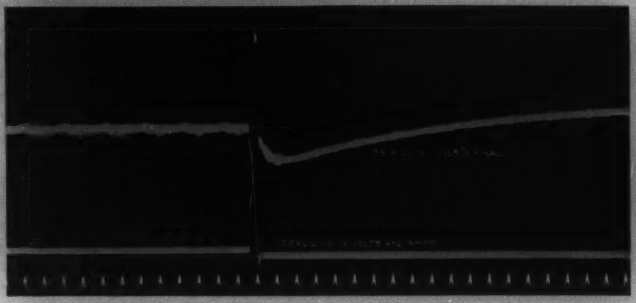


Figure 3 (below). Oscillogram of voltage on short to open circuit test on 200-ampere welding generator

sirable. Although it is improbable that the penetration is improved by these fluctuations, strange as it may seem, there is something to be said for each of these contradictory claims.

It should be understood that there are two sources of current fluctuation when the arc is short circuited. The current may increase because the permanent short-circuit current on the volt-ampere characteristic is considerably higher than the current at welding voltage. The current increase may also be produced by a transient overshoot, which will be large if the transient characteristic of the machine is poor. It is the former type of fluctuations which is the subject of this discussion, as no one will claim any advantage for the latter type.

It is not likely that any great benefit is derived from these fluctuations in producing better penetration. Since the first draft of this manuscript was submitted, an article has appeared which completely verifies this intuitive statement.[1] However, they do serve a useful function, which will be discussed later, but they must be kept within certain limits or they become harmful.

It is generally agreed that oscillograms of arc current and voltage when welding are useful in comparing the performance of two machines if they can be tested under identical conditions. However, they are not well adapted to serve as a basis for specifications to cover the transient performance of a welding generator. To answer this purpose the test must be of such nature that it can be duplicated anywhere under certain prescribed conditions.

Inadequacy of Present Specifications

It is natural that specifications which have so far been formulated to cover tests for transient performance of welding generators should simulate as far as possible the conditions prevailing in the arc. That is, oscillograms are taken of the current while the external resistance undergoes a prescribed variation. For example, the AIEE test of a welding generator for momentary current fluctuations and arc recovery is as follows.

Adjust generator on resistance load to obtain normal current at 25 volts. Short-circuit one half the resistance and allow current to settle. Then suddenly open the short circuit and reinsert the resistance in the circuit. The current momentarily drops below normal and the time of recovery is the time required for the current to return to within five per cent of its original value. The resistance variation prescribed by this specification is so narrow as to preclude its being of any use.

Another specification for arc recovery states that the machine should be loaded on a resistance to give 40 volts across the resistance and a current corresponding to the setting at which the test is made. The entire resistance is then short-circuited and the conditions allowed to become stable. The short circuit is then suddenly opened, reinserting the resistance. The momentary current drop should not fall below 70 per cent of normal and the current should be back to within five per cent of normal in not more than 0.3 second.

Figure 2 shows an oscillogram made according to this test on a 200-ampere machine at full load.

This test is an improvement on the AIEE specification in so far as the prescribed resistance variation is wide enough to produce an appreciable current fluctuation. However, the usual interpretation of this test leaves much to be desired. Experience has shown that a machine which meets this specification may be definitely inferior to one which does not, and vice versa. The requirement that the current should return to within five per cent of normal in not more than 0.3 second is a particularly valueless stipulation, inasmuch as the disturbances in the arc occur at much shorter intervals than 0.3 second. What

happens on a test of this kind after, say 0.1 second, is of no interest. This test unquestionably has some merit, but it is felt that it may be interpreted in a manner to give it greater usefulness than has so far been the case.

In addition to specifications for current recovery, there is at present in existence a specification for voltage recovery. It states that when a machine is suddenly open circuited from short circuit the time of voltage recovery is the time required for the voltage to reach 50 per cent of normal open-circuit voltage. Figure 3 shows an oscillogram of voltage recovery from short circuit. The test itself is valuable and gives more information about the transient performance of the machine than the other tests discussed, but the definition of voltage recovery given above is absolutely valueless.

It will be observed that the voltage rises quickly to a high value, then drops to a comparatively low value, from which it gradually recovers to normal. The rapidity with which the first rise of voltage takes place depends entirely upon the rapidity of the break of the current. This is the voltage induced by the rapid change of current in an inductance and it will be instantaneous if no arc is formed at the break, or if means are employed to blow out the arc if one is formed. In general, this voltage rise reaches a maximum when the current reaches zero, and the time required to reach this maximum is of no value as a criterion of performance of the machine, but its magnitude is of great importance. The peak value of this first voltage rise should always be considerably higher than the normal open-circuit voltage, and if the time required to reach this peak is of no importance, the time required to reach 50 per cent of normal can certainly have no significance.

The minimum value to which the voltage drops after the first sudden rise is an indication of the building-up characteristic of the fields. The higher this value is maintained, the faster the fields build up to produce a sustained voltage. As before, the gradual increase in voltage after this minimum voltage is passed is of little significance. It is the magnitudes of the maximum and minimum voltages on this test that are of importance. They are indications of the machine's ability to react quickly to sudden current changes by virtue of an appreciable amount of inductance in the circuit, and also the ability of the field to build up rapidly enough to sustain the voltage after the quick change has taken place. It will be shown later how this test, taken in conjunction with the previously discussed load test, can be interpreted to give a clear picture of the entire transient performance.

A Prerequisite for Arc Stability

Experience gained from many years of operation of constant-potential welding generators furnishes a clue to the reason for failure of the current-recovery test described above to tell the whole story. On a test of this kind the constant potential machine, where the drooping volt-ampere curve is produced by inserting resistance in series with the arc, will show 100 per cent current recovery. It shows no overshoots or under-rides on the recovery test.

Likewise, on the voltage-recovery test, the constant potential machine will show instant recovery to full open-circuit voltage. This, of course, is evident. Yet, experience showed that a variable voltage machine in which the drooping volt-ampere characteristic is produced by magnetic means frequently performed better on actual welding, even though it has considerable overshoots and under-rides on the current-

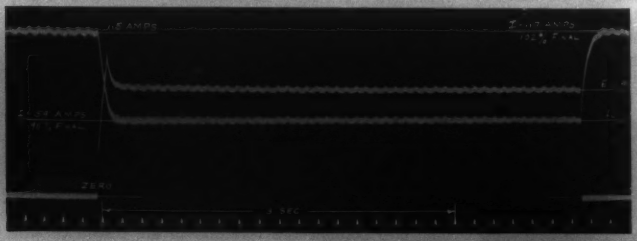


Figure 4 (above). Oscillogram of current and voltage on short to load test on 200-ampere welding generator set; 60 amperes, 40 volts

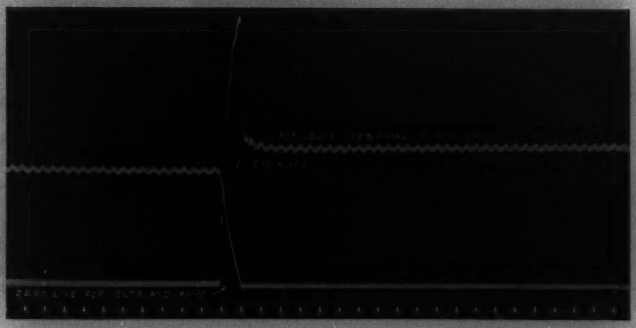


Figure 5. Oscillogram of voltage on short to open test on 200-ampere welding generator

recovery test. Furthermore, experience also showed that the operation of the constant potential machine was markedly improved by insertion of a certain amount of inductance in the circuit, especially if the volt-ampere characteristic is fairly flat.

Figure 4 shows an oscillogram of a current-recovery test on a 200-ampere machine with sufficient resistance in the circuit to give it the constant potential characteristic. However, it is also supplied with an inductive stabilizer. It will be observed that the current drops from the short-circuit current to normal with practically no dip. Without the inductive stabilizer in the circuit, substantially the same current-recovery curve would be obtained. However, the insertion of the inductance modifies the voltage curve very materially. Without the inductance the voltage would rise quickly to normal and stay there. With the inductance in the circuit the voltage rises rapidly to a value considerably above normal before settling down. This overshoot of voltage when there is a sudden reduction in current is apparently of great benefit in stabilizing the arc.

Similar phenomena will also be observed on the voltage recovery test on the same machine shown in figure 5. Without the inductance the voltage would rise to the normal open-circuit voltage without overshoot. With the inductance, a higher voltage peak is obtained.

These observations merely verify the familiar fact that the more electromagnetic energy there is stored in an electric circuit, the greater is the tendency to establish an arc when the circuit is broken. When a drop of metal forms a short circuit the arc is extinguished and the high instantaneous voltage induced when there is a sudden reduction in current is a direct measure of the tendency to re-establish the arc upon the reopening of the arc gap. The minimum sustained voltage is a measure of the tendency to maintain the arc once it has been established.

Figure 6. Oscillogram of voltage on short to load test on 400-ampere welding generator set at 400 amperes, 40 volts

The importance of the magnitudes of these voltages can, therefore, readily be appreciated.

Long experience with another type of equipment points in the same direction. In endeavoring to apply a-c current to arc welding it was soon discovered that a drooping volt-ampere characteristic produced by resistance in series with the arc, similar to the constant-potential d-c system, was of practically no value in bringing about arc stability. On the other hand, when the drooping volt-ampere characteristic was produced by reactance in either primary or secondary circuit, the arc stability was greatly enhanced.

With resistance in the circuit, the power factor is high, and the secondary voltage and current rise and fall practically in unison. When the current passes through the zero point the arc goes out and the voltage rise following an approximate sine wave is too slow to re-establish the arc, and it stays out. With reactance in the circuit the power factor on the input side is low and on the output side the voltage wave is distorted into an almost rectangular shape, frequently with a sharp peak on the leading side of the rectangle. This abrupt rise of voltage immediately after the current passes through the zero point is an essential requirement to quickly and surely reignite the arc. The inference from experience, therefore, is that whenever the arc has gone out for any reason, such as being short-circuited by a drop of metal in d-c welding or the current passing through zero in a-c welding, a rapid rise of voltage to a relatively high value, even if of short duration, is a necessary requisite for the reignition of the arc, and therefore highly desirable.

The theory of the arc, as it has been developed so far, appears to agree with experience. According to Doctor C. G. Suits,[3] the resistance of the arc depends on the state of ionization of the gaseous medium, which in turn depends on the ionizing voltage and the temperature. Furthermore, the ionization follows a variation in the temperature almost without time lag, the period of readjustment being of the order of 0.001 second. The short circuiting of the arc by a drop of metal and the consequent momentary extinction of the arc is unquestionably followed by a drop in temperature of the surrounding gases.

The initial resistance of the arc upon the reopening of the arc gap as the drop leaves the electrode is, therefore, considerably higher than the average arc resistance. A rapid and relatively high voltage rise at that instant is then effective in reducing the initial resistance by rapidly increasing the state of ionization of the arc gases. The failure of the current-recovery test, as interpreted at present, to give a correct picture of the transient performance, is undoubtedly due to the fact that it does not take into account the variation in arc resistance with temperature and applied voltage. To give this test the maximum of usefulness, the voltage fluctuations which take place when the test is made should also be taken in consideration.

Transient or Dynamic Volt-Ampere Curves

As the maximum and minimum voltages induced when there is a sudden interruption of the circuit, or a sudden insertion of a resistance in the circuit, are determining factors in producing arc stability during welding, these values plotted in the form of curves similar to the static volt-ampere curves should prove of interest. The open-circuit points for these curves are obtained from the voltage-recovery test already described. The load points are obtained by tests similar to the current-recovery tests,

except that oscillograph records are made of the voltage only. The machine is loaded on resistance, which gives a point on the static volt-ampere curve. The resistance is then short-circuited and conditions allowed to become stable. The resistance is then suddenly opened and a record made of the maximum and minimum voltages, as shown in figure 6. In making this test the film should travel fast to obtain a distinct maximum voltage point, also the short should be interrupted quickly. If necessary, a blowout of the arc should be provided. The resistance is then varied in suitable steps and the test repeated.

Figure 7 shows the static and transient volt-ampere curves for approximately full load setting of a 400-ampere welder. The curves give a clear picture of what happens when a resistance is suddenly inserted from a short circuit. While the current drops quickly from the steady short-circuit value, the voltage rises quickly along curve 2, reaching point *A* approximately at the time the current has dropped back to normal. From this point on the current drops slowly. The voltage at first drops quickly along *ab* until the current and voltage simultaneously reach their minimum values at *B*. From there on they increase rather slowly along *bc* to *C*. As pointed out, this gradual approach back to normal is of no significance. The point *B* can readily be determined from the fact that the percentage reduction in current is substantially equal to the percentage in voltage below normal. This eliminates the necessity for recording the current with the oscillograph and simplifies the operation considerably.

Curve 1—Transient volt-ampere curve of momentary short-circuit current values
Curve 2—Volt-ampere curve of transient peak voltages obtained during change from short-circuit condition to a resistance load condition
Curve 3—Volt-ampere curve of static or steady-state conditions obtained by various resistance loads
Curve 4—Volt-ampere curve of minimum voltage obtained when changing from short-circuit condition to a given resistance load condition

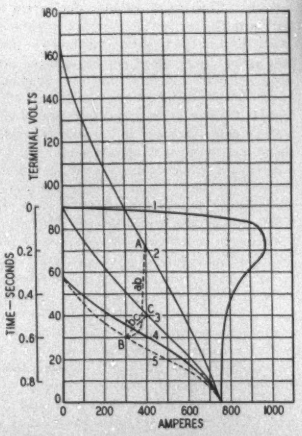


Figure 7. Transient and static (steady-state) volt-ampere characteristics of 400-ampere welding generator

It can readily be seen that the steady short-circuit current must be appreciably higher than the welding current in order to induce a high substantially instantaneous voltage when a resistance is suddenly inserted in the circuit. On the other hand, it is desirable to keep the current fluctuation from becoming excessive when a sudden short takes place. Recent tests have shown that large short-circuit currents tend to produce weld metal of large grain size with poor impact value and greatly increased spatter loss. For convenience, the record of the current when the machine is suddenly shorted from open circuit may be plotted on the same sheet as shown by curve 1. The overshoot is in this case higher than it would be if the short was made from a resistance load at lower voltage, but it represents the possible maximum current fluctuation and is, therefore sufficient.

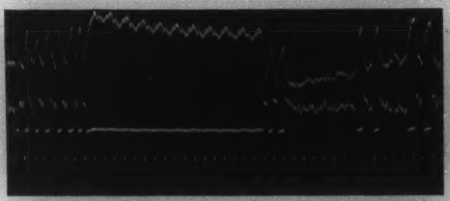


Figure 8. Oscillogram of arc current and voltage when welding with three-sixteenths-inch bare electrode. Approximately 160 amperes, 20 volts

The degrees of steepness of curves 2 and 5 are the important factors in determining arc stability. Of course, the degree of steepness has no meaning unless the scales of co-ordinates are agreed upon. However, the ratio of volts to excess of short-circuit current over normal current may be taken as the measure of steepness. For example, the curves in figure 7 were taken at 400 amperes, 40-volt setting. At 400 amperes curve 2 shows a voltage of 72 volts; 72 divided by (760 − 400 = 360 amperes) = 0.2. In the same manner the steepness factor of curve 5 is 0.0695.

A moderately steep static volt-ampere curve together with a much steeper curve 2 produces a very desirable characteristic. The steepness of curve 2 is very effective in producing arc stability provided the arc length is kept within certain limits. At the same time, the moderate steepness of curve 3 precludes an excessively long arc. In many applications the operators have to break the arc frequently and they prefer a clean break when the arc is drawn beyond a certain length, but they also desire the arc to hang on tenaciously within that length. A wide spread between curves 2 and 3 is conducive to this desirable feature.

It is interesting to observe the voltage peaks resulting from a rapidly decreasing current when welding with a machine with good transient characteristics. Figure 8 shows these peaks distinctly and is especially interesting as the operator happened to short-circuit the arc when the film was taken. The sharp voltage rise after each short circuit as the drops go across is indeed the most important

criterion in judging the transient performance of a welding generator from an oscillogram taken while welding.

Bibliography

1. Influence of Volt-Ampere Characteristics on Penetration, N. Frazer. *The Welding Journal*, November 1937.

2. High Pressure Arc, C. G. Suits. *General Electric Review*, April 1936.

Discussion

R. C. Freeman (nonmember; General Electric Company, Schenectady, N. Y.): The article shows two important features of the voltage-recovery characteristics of a d-c power source for arc welding, graphically represented on the basis of the same voltage ordinates and current abscissas as are used for the static volt-ampere curves.

The prime importance of various recovery characteristics has long been recognized by those acquainted with the design and operation of arc-welding generators. There has been much discussion as to the relative importance of the different features of voltage and current recovery under variously specified conditions. From the extensive experience of many engineers there has developed the consensus that peak-voltage recovery, or certainly the constants indicated by the presence of such a voltage surge, and minimum voltage recovery are two of the most significant phases of the transient phenomena.

The transient characteristics of a welding generator as graphically represented in figure 7 of the article, would become more meaningful if the time element were evaluated. This is particularly true in curve 2 of figure 7 which is a plot of transient peak-voltage values. Since this peak voltage is an electromotive force induced by the rapid change of current when a short circuit of the generator is completely opened or opened across some predetermined resistance, this value then is a function not only of the constants of the welding generator but also of the speed of opening of the short circuit. Significant though such peak values are, they do not lend themselves to a simple and accurate quantitative determination of the welding-generator constants which are necessary for the maintenance of a good welding arc.

The author minimizes the significance of the time element in the ultimate recovery and current to steady-state values. Although the magnitude of minimum voltage recovery is of much more importance in the maintenance of an arc, yet it is also true that the time required for the current in the arc to recover to a normal value (that is, the time required for the transition from point *B* on curve 5 to point *C* on curve 3 of figure 7 of the article) is worthy of consideration as a means of obtaining more uniform welding performance. It is noteworthy that in the ultimate recovery of current and voltage (to point *C*, figure 7) from the minimum value (point *B*, figure 7) there is an increase of 75 per cent in the watts of electrical energy delivered to the arc. Obviously it is advantageous to complete a transition of such proportion in a minimum period of time.

In a time where there are so many conclusions drawn and claims made regarding welding performances which are based upon only a superficial consideration of static volt-ampere curves, this article stands for a true analysis of arc welding performance based upon the all-important consideration of transient characteristics.

K. L. Hansen: The maximum and minimum voltages following the sudden insertion of a resistance in the circuit are apparently recognized as the most important criteria in judging the welding performance of a generator. However, Mr. Freeman is skeptical about the ability to determine the peak voltages readily and with a reasonable degree of accuracy. He is of the opinion that the magnitude of the voltage peak is materially influenced by the time element involved in breaking the circuit.

It is true that the time required for the voltage to reach its maximum value on the short-circuit-to-open-circuit test is directly dependent on the rapidity of the break. In general, the voltage reaches the peak when the current has dropped to zero, as stated in the paper. But, strange as it may seem, the magnitude of the voltage peak is by no means inversely proportional to the time required for the current to reach zero, although it is considered to be induced principally by this rate of current change. This point was brought out rather forcibly by a test made some years ago.

In discussing my paper ("Recent Developments in Design of Arc Welding Generators," AIEE Transactions, June 1932, page 576), Mr. Ver Planck contended that a "slow" break would assist the generator in maintaining a high minimum sustained voltage in so far as it gave the generator fields more time to build up. He compared the oscillogram of a recovery test shown in my paper with one taken on a Bergman machine and found that the short circuit was interrupted six times more slowly on the Hansen machine. This, Mr. Ver Planck claimed, assisted the Hansen machine in showing a high "minimum recovery" voltage.

This point was carefully checked by repeating the test on the Hansen machine and taking special precaution to break the arc quickly. The rate of breaking the current was speeded up to compare with the test on the Bergman machine, that is, about six times faster than on the recovery test shown in the paper. In spite of the greatly increased rate of current change, the peak voltage was only about 30 per cent higher and the minimum recovery voltage, instead of being lower as Mr. Ver Planck expected, was a few volts higher. Here a greatly increased rate of current change produced only a moderate change in the peak value of the voltage and a very slight change in the minimum value. It is their comparative freedom from dependence upon the rate of interruption that led me to propose the consideration of the magnitudes of the peak and minimum voltages on the recovery tests rather than the ridiculous stipulation of "the time required to reach 50 per cent of normal voltage."

When the short circuit is opened on a predetermined resistance the importance of the time element in affecting the magnitude of the voltages is less than when the circuit is completely opened, and the lower the value of the resistance on which it is opened the less important the time element becomes. The tendency to form an arc when a circuit is opened is greatly minimized when a circuit of low resistance is connected in parallel with it.

Possible errors in the peak-voltage values due to variation in the rate of interruption, therefore, become progressively smaller for lower points on curve 2. That is fortunate because it is the steepness of this curve over the welding range that is of importance. What happens as the curve approaches the open-circuit point is not of much consequence. The fact that the peak values come out on a smooth curve is an indication that they cannot be very erratic. It is certainly easier to determine the voltage peaks than the gradual approach to within five per cent of normal current on the present current recovery test.

Mr. Freeman's second criticism that little consideration is given in the paper to the time of current recovery deserves to be commented on. Mr. Freeman states that there is an increase of 75 per cent in the energy delivered to the arc as the current and voltage pass from their minimum values to normal.

This statement is evidently based on the assumption that the behavior of the current and voltage is the same when a fixed resistance is inserted in the circuit as it is when the arc gap is opened due to a drop leaving the electrode. This, however, is far from being the case, as pointed out in the paper. A close study of many oscillograms taken during actual welding operations has not disclosed any tendency for the current and voltage to start at low values and gradually approach normal after recovering from a short circuit caused by a drop. Even when there is no drop passing across for as many as 10 to 12 cycles there is no evidence of such a tendency. The reason probably is that the conductance of the arc is itself a function of the applied voltage. A high peak value of voltage following immediately upon the opening of the short circuit appears to establish normal current flow quicker in the arc than it does in a fixed resistance. This is the reason that so little consideration is given in the paper to the time of current recovery when it is taken on a resistance.

Co-ordination of Power Transformers for Steep-Front Impulse Waves

By V. M. MONTSINGER
FELLOW AIEE

Introduction

THE REQUIREMENT that transformers withstand certain specified impulse tests has been accepted by the industry as desirable, and the Institute has recommended a standard method of testing transformers with a 1.5 x 40 microsecond wave.

These tests, however, do not demonstrate that transformers can withstand steep-front waves when the voltage is limited by flashover of their bushings or of rod gaps that give ample protection for long waves. The reason, of course, for this is that the flashover voltage of an air gap increases faster than the breakdown voltage of insulation as the time (to flashover or breakdown) gets shorter. This means that the margin of safety of the transformer, when protected by an air gap, decreases as the impulse wave front becomes steeper and for very steep fronts the margin may disappear. It is now generally recognized that to protect a transformer by an air gap against steep front waves, the spacing of the gap must be much lower than that necessary to protect against long waves.

Furthermore, in cases where transformer windings have an inherently poor initial impulse voltage distribution at the line end, the steep-front waves produce steeper gradients (in per cent of the applied wave) than are produced by long waves with the result that breakdown may occur between the turns and coils, before the major insulation fails. This is particularly true of the higher-voltage unshielded windings. In such cases shorter air gaps may be required to protect the line end coils than are required to protect the major insulation.

Though greatly improved in impulse strength, within the past few years, it has to be admitted that modern high voltage transformers cannot withstand the kilovolts associated with excessive steep-front lightning waves resulting from direct strokes on or near its terminals. The major insulation would fail. Transformers, of course, could be built to withstand direct strokes but this cannot be economically justified. Extremely steep-front waves should, of course, be kept out of the station by suitable means and suitable protective devices used for protection against dangerous incoming traveling waves.

Finally, to co-ordinate or protect transformers intelligently for all kinds of impulse waves requires an accurate knowledge of the volt-time characteristics of transformer insulations. Data of this kind can be determined only by careful laboratory investigations of typical transformer insulations. Such investigations have been under way during the past few years.

Paper number 37-136, recommended by the AIEE committee on electrical machinery and presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Manuscript submitted October 13, 1937; made available for preprinting November 23, 1937.

V. M. MONTSINGER is a research engineer for the General Electric Company, Pittsfield, Mass.

1. For all numbered references, see list at end of paper.

Purposes of Paper

The purpose of this paper is to report the results of these laboratory tests made to determine the impulse volt-time curve characteristics of transformer insulations, based upon the effect of both single and repeated applications of impulse voltages on both the corona injury level and the breakdown. Front-of-wave testing of transformers is also discussed.

A. Volt-Time Characteristics of Transformer Insulations

Considerable data have already been published[1–4] on volt-time curves of solid insulation, on transformer oil and

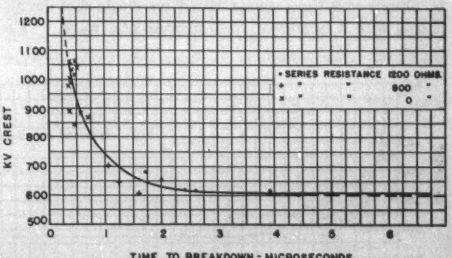


Figure 1. Single-shot volt-time curve of barrier A (36 inches by 48 inches). One-quarter inch oil plus one-eighth inch P. B. plus one-quarter inch oil plus one-eighth inch P. B. plus one-quarter inch oil—total thickness one inch, four-inch-diameter square-edged electrodes, 1.5 x 40 negative wave

on solid insulation in series with oil (representing the major insulation in a transformer). Most of these curves were based upon breakdown caused by a single application of voltage for the various "times to breakdown." Unlike an air gap, insulation has the characteristic of being weakened by repeated applications of voltage above the injury level. Therefore, in comparing the volt-time curve of transformer windings with air gaps, it is quite necessary to use insulation curves based upon repeated voltage applications for the reason that we have no assurance that a transformer will not be subjected to more than one lightning stroke. In fact, it has been shown[6] that in a (supposedly) single stroke a large number of impulses may

follow each other in rapid succession. Another reason why co-ordination and protection should be based upon the "repeated impulse wave" volt-time curves of insulation is that the application of a single wave having an amplitude higher than the repeated wave strength will cause injury even though failure does not occur.

Insulation Barriers

Tests were made on four different barriers designated as *A*, *B*, *C*, and *D*, designed to simulate the major insulation in transformers. Barriers A and B in all cases had bare electrodes. Barriers *C* and *D* had insulated line (generator-side) electrodes and a flat metal sheet for ground electrodes.

Tests on Barriers *A* and *B*

Barrier *A* consisted of one-fourth inch oil, one-eighth inch pressboard, one-fourth inch oil, one-eighth inch pressboard, and one-fourth inch oil—total thickness of barrier of one inch. Barrier *B* was the same as *A* except that it consisted of one-eighth inch oil ducts and one-sixteenth inch pressboard sheets—total thickness one-half inch. In all cases the oil ducts were maintained by two spacing strips one-half inch in width under the electrodes.

(*1*). *Single-Shot Breakdown Volt-Time Curves.* Figures 1 and 2 give the results of tests made on barriers *A* and *B* to obtain volt-time curves based on single-shot breakdowns with a negative 1.5x40 microsecond wave. The

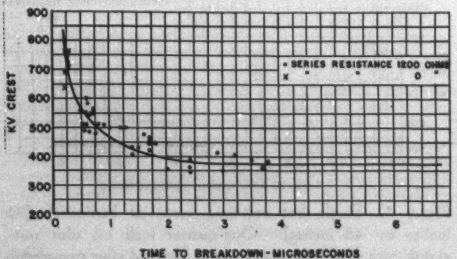


Figure 2. Single-shot volt-time curve of barrier B (36 inches by 48 inches). One-eighth inch oil plus one-sixteenth inch P. B. plus one-eighth inch oil plus one-sixteenth inch P. B. plus one-eighth inch oil—total thickness one-half inch, four inch diameter square-edged electrodes, 1.5x40 negative wave

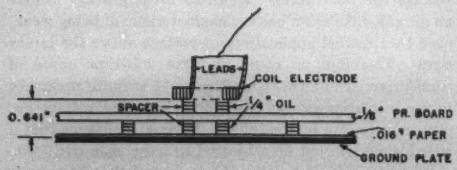
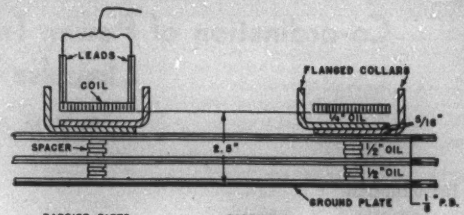


Figure 3. Insulation barrier C used for dielectric tests



BARRIER PARTS	BARRIER C	BARRIER D
COIL CONDUCTOR	.300 X .120"	.300 X .100"
COIL INS. (ONE SIDE)	(.006" PAPER (.003" COTTON	(.138" PAPER (.003" COTTON
COIL DIAMETER (INSIDE)	4.0"	9.25"
COIL RADIAL BUILD	1.875"	1.875"
SIZE OF PRESSBOARD	36 X 48"	36 X 48"
SIZE OF GROUND PLATE	36 X 48"	36 X 48"

Figure 4. Insulation barrier D used for dielectric tests

line and ground electrodes were four inch diameter disks with square edges.

Expressed in percentages of kilovolts versus time to breakdown the curves in figures 1 and 2 give the values shown in table I.

(*2*). *Life Tests With Full Waves.* To obtain the effect of repeated shots on the breakdown strength as compared with the single-shot strength with a 1.5 x 40 wave, several thousand shots (covering a period of about one year) were made on barriers of type *A*. Three shapes of line electrodes were tried out, these being (1) four-inch-diameter square edge; (2) rectangular U-shaped rods; and (3) one inch round U-shaped rods. The rectangular and round rods were well rounded at the bends. The ground electrode was a metal sheet 36 inches by 48 inches.

The only definite conclusions that could be drawn from these life tests were, first, that on repeated shots the "wait" between shots apparently had no effect on the final breakdown value. In other words, there appears to be no heating effect with impulse voltages as occurs with low frequency voltage.[6]

Second, the breakdown value was reduced (below the single-shot value) quite rapidly on the first few shots, approximately 50 per cent of the reduction occurring in the first ten shots and then decreasing to the final or minimum breakdown value in the next 25 or 50 shots.

No dependable curve of breakdown versus number of shots could be obtained for the reason that injurious corona in some cases started as low as 60 to 65 per cent of the single-shot breakdown value, but failure did not usually occur (under many shots) until approximately 90 per cent of the single-shot breakdown value was reached. Obviously, when the insulation was tracked near the line electrode at 65 to 75 per cent voltage the final breakdown value of approximately 90 per cent voltage did not mean anything. Apparently dependable life tests cannot be obtained with bare line electrodes. This, of course, is not a practical condition as all transformer conductors are insulated.

Tests on Barriers *C* and *D*

At this point it was decided to use insulated line electrodes or small coils with barriers, designated previously as *C* and *D*.

Table I. Impulse Volt-Time Values by Test

Time to Breakdown (Microseconds)	Kilovolts in Per Cent of Full-Wave Kilovolts
0.25	200
0.5	150
1.0	125
1.5	113
2.0	105
Full wave	100

Barrier *C* consisted of a small coil as the line electrode and a plane as the ground electrode, the two electrodes being separated 0.641 inch consisting of one-fourth inch oil, one-eighth inch pressboard, one-fourth inch oil, and a 0.016 inch sheet of paper adjacent to the ground plate. See figure 3. The turns in the coil consisted of 0.300-inch by 0.120-inch copper strands insulated with 0.006 inch paper (one side thickness) and 0.003 inch cotton thread, the cotton serving merely as a mechanical protection. This barrier represents the type of major insulation of approximately a 15-kv power transformer.

Barrier *D* consisted of a small coil (more heavily insulated than the one in barrier *C*), a one-fourth inch oil duct adjacent to the coil, two five-sixteenth inch flanged collars, (5) one-eighth inch pressboard sheets, and two one-half inch oil ducts—total thickness two and one-half inch—as shown in figure 4. The turns in the coil consisted of 0.300 inch by 0.100 inch copper strands insulated with 0.138 inch paper (one side thickness) and 0.003 inch cotton thread. This barrier represents the type of major insulation of a power transformer of approximately 92-kv rating.

Figure 5 shows the impulse generator and circuit connections used.

Twenty or more *C* barriers were tested—some on life tests of several hundred shots—before consistent results could be obtained. The difficulty was found to be due to small particles of air entrapped in the coil insulation. The presence of air was very misleading both in the beginning of corona and in the breakdown strength. Quite often, on repeated shots the first appearance of corona gradually disappeared. This process might occur several times as the voltage was increased. During this time the air was eliminated.

As it was not practicable to eliminate the air in the manner usually employed in transformers (by short-circuit heat runs, or evacuation) before starting the tests, it was necessary to assemble the barrier under oil. The coils were dried, oil impregnated, and kept under oil at least 24 hours previous to use and not allowed to come in contact with air during the assembly process. The pressboard, paper sheets, flanged collars, and spacers were all vacuum dried and oil impregnated, and assembled under oil. Approximately 6,000 shots were made on barrier *C* alone after the entrapped air problem was solved. Approximately 4,600 shots were made on barrier *D*. Altogether during the entire investigation some 15,000 to 20,000 impulse tests were made, ranging over a period of approximately two years' time. The investigation proved to be one of the most difficult ones ever followed by the author.

The results of the tests made on barriers *C* and *D* are shown in curve form in figures 6, 7, and 8. The full-wave points are shown at from four to five microseconds' time, regardless of the exact point on the wave at which either corona, injury, or breakdown occurred. The corona no doubt occurred near the crest of the wave (approximately 1.5 microseconds). As has been pointed out, breakdown of insulation barriers also usually occurs near the crest of the wave, though in some cases it may be somewhat beyond the crest—perhaps up to two or three microseconds for a 1.5-microsecond front. Each point represents anywhere from 20 to 100 shots and in some cases several hundred shots were made in graduated steps before corona, injury, or breakdown occurred.

Table II. Impulse Ratios

Negative Full-Wave Impulses	Impulse Ratios for Barriers C	D
1. Single-shot breakdown to one-minute 60-cycle breakdown	$\left(\frac{320}{155}\right) = 2.07$	
2. Repeated shot breakdown to one-minute 60-cycle breakdown	$\left(\frac{280}{155}\right) = 1.8$	$\left(\frac{780}{300}\right) = 2.6$
3. Injurious corona impulse to injurious corona 60 cycle	$\left(\frac{240}{137}\right) = 1.75$	$\left(\frac{680}{275}\right) = 2.48$
4. Injurious corona impulse to one-minute 60-cycle breakdown	$\left(\frac{240}{155}\right) = 1.55$	$\left(\frac{680}{300}\right) = 2.27$

All front-of-wave tests, with one exception, were made by chopping the wave with either 100-centimeter or 200-centimeter spheres. The front of the wave chopped with spheres had no bend-over, as often occurs when chopped with a rod gap. No gap was used when obtaining the single-shot breakdown volt-time curve shown in figure 6, the applied wave being raised on a new barrier after each breakdown. The time and kilovolt values at breakdown were obtained by cathode-ray oscillograms.

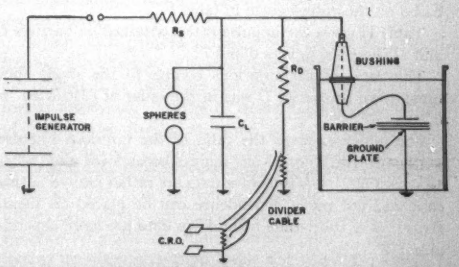


Figure 5. Impulse generator and circuit connections for testing insulation barriers

The curves shown by dashes in figures 6, 7, and 8 and

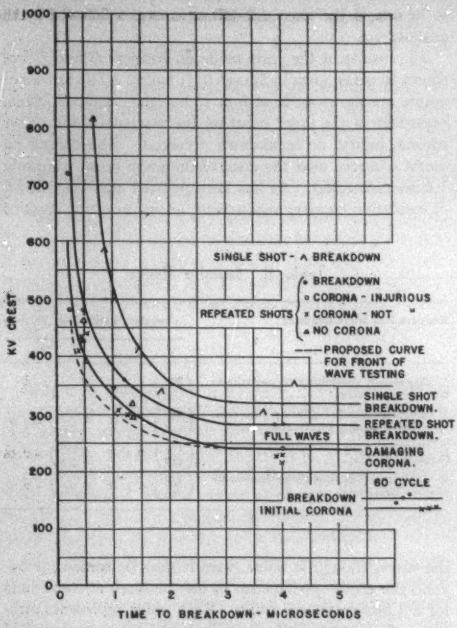


Figure 6. Volt-time curves of transformer insulations; impulse tests on 0.64 inch barrier C; negative waves; 1.5 x 40 used on full-wave tests

marked "Proposed curve for front-of-wave testing" are based on the values given in table I.

Table II gives the impulse ratios obtained on barriers *C* and *D* shown in figures 6 and 7.

The ratio of the injurious corona to the single shot breakdown of barrier *C* was in the order of (240/320) = 0.75.

For positive waves the ratio of the injurious impulse voltage to the 60-cycle one-minute breakdown was (235/-155) = 1.52. The full-wave data are rather limited in this case and not much dependence can be placed on them. (Note: The short-time breakdown data are more dependable.)

The results of this investigation indicate that there is no definite impulse ratio that applies to all voltage ratings of transformers.

B. Testing Transformers on Front of Wave

If front-of-wave testing is to be standardized, careful consideration must be given to the rate of voltage rise to be used. Just how steep a wave front should be for front-of-wave testing is an open question. It is not felt that enough is known at the present time of the steepness of wave fronts that occur under service conditions and especially whether or not the same steepness of fronts occur on all rated voltage circuits to make any definite recommendations at this time. The suggestion, however, has been made that a wave whose front rises at the rate of 1,000 kv per microsecond be used for front-of-wave testing of transformers of all voltage ratings. In fact, several high-voltage transformers have recently been tested with this wave by flashing over a rod gap having a spacing in the order of 70 per cent of the (previously standard) test gap.[7]

The present knowledge of direct strokes indicates that the rate of voltage rise is not constant over the whole front of the wave, being lower at the initiation of the wave. Since the same kind of lightning waves will strike both low- and high-voltage circuits, the rate of rise to flashover of the line or station insulation would be less for low-voltage circuits. If 1,000 kv per microsecond is correct for high-voltage circuits it may be only 500 kv per microsecond for low-voltage circuits.

Service records on old transformers protected only by gaps coupled with experience in making factory impulse tests (using 1,000 kv per microsecond wave fronts) on transformers of relatively high-voltage ratings and of similar construction and insulation levels, indicate that seldom are wave fronts as steep as 1,000 kv per microsecond imposed on transformers in service. In other words, based on laboratory tests many of these old transformers would fail if subjected to 1,000 kv per microsecond wave fronts. This absence of failures might be accounted for by the fact that the wave fronts are usually sloped off to less than 1,000 kv per microsecond by attenuation or by the station capacitance—of bus bars, bushings (for both circuit breakers and transformers) and of the

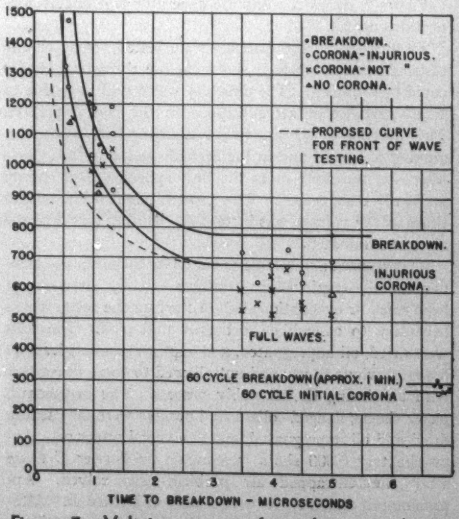


Figure 7. Volt-time curves of transformer insulations; impulse life tests on 2.5 inch barrier D; negative waves; 1.5x40 used on full-wave tests

transformer windings. This indicates that 1,000 kv per microsecond rate of voltage rise might be too high for front-of-wave testing, especially for transformers of the lower voltage ratings.

Front-of-wave testing can be specified in either of two ways; first, by kilovolts and time; second, by inches of rod gap and rate of voltage rise. In either case the kilovolts imposed on transformers in front-of-wave testing should be governed by the volt-time curve of transformer windings if the same factor of safety is to be maintained for full waves, chopped waves, and front of waves. Until the EEI-NEMA subcommittee on correlation of laboratory data establishes volt-time curves for gaps, insulators, etc., it appears that some front-of-wave tests will be specified by gap spacings. The preferable method, however, is to specify the tests by kilovolts and time to flashover of a gap.

Specifying front-of-wave testing by inches of rod gaps is more involved than specifying the test by kilovolt values for the reason that the proper gap spacing depends upon the way the rate of rise is defined. There are two ways of defining the rate of rise; namely,

First, the rate of rise is determined by the slope of a straight line drawn through the 10 and 90 per cent voltage points. This is usually termed the "effective" rate of rise.

Second, the rate of rise corresponds to the slope of a straight line drawn from virtual zero to the time of actual flashover. This is termed the "average" rate of rise.

NOTE: In either case "time" starts from "virtual time zero" which is determined by drawing a straight line through the 10 and 90 per cent voltage points. The intersection of this line with the time axis (zero voltage line) is the virtual time zero.

If there is no bend-over just before flashover, both the effective and average rates of rise are, of course, the same.

However, when using a rod gap to chop the wave front, there may be an appreciable bend-over just before flashover takes place (due to heavy corona current drawn by rod gap), in which case the effective rate of rise will be greater than the average rate of rise. This is illustrated in figure 9. Merely applying a higher voltage will not entirely eliminate the bend-over.

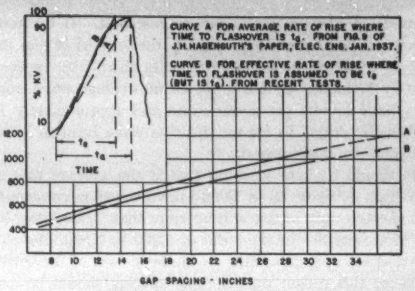

CURVE A FOR AVERAGE RATE OF RISE WHERE TIME TO FLASHOVER IS t_a. FROM FIG. 8 OF J.H. HAGENGUTH'S PAPER, ELEC. ENG. JAN. 1937.
CURVE B FOR EFFECTIVE RATE OF RISE WHERE TIME TO FLASHOVER IS ASSUMED TO BE t_a (BUT IS t_a). FROM RECENT TESTS.
% KV
TIME
A AVG.
B EFF.
KV
GAP SPACING - INCHES

Figure 9. Impulse flashover of rod gaps, 1,000 kilovolts per microsecond, negative wave fronts

The remainder of the discussion of this subject will be based, merely for illustrative purposes, upon testing transformers with a 1,000 kilovolts per microsecond wave front. It should be understood, however, that this does not mean that a 1,000 kilovolts per microsecond wave is advocated for front-of-wave testing for the reasons previously mentioned. If some other rate is used where the test is specified by gaps, the same method should be used to determine the proper gap spacing.

The impulse flashover of rod gaps at 1,000 kilovolts per microsecond wave front is shown in figure 9, where curve *A* is based on the average front and curve *B* on the effective front.

Curve *A* is based on three points for 10-, 20-, and 30-inch gap spacings taken from figure 9 of reference 8. Curve *B* is based on two points for 10-inch and 24-inch rod gaps recently taken in the Pittsfield works high-voltage laboratory.

As previously pointed out the proper kilovolts to use for front-of-wave testing of transformers with standard insulation should be based on the volt-time curve of transformer insulation. Figure 10 shows the volt-time curves of transformer insulation based on (1) breakdown by single application of voltage, curve *A*, and (2) breakdown by repeated applications of voltage, curve *B*.

We are now in a position to select the proper kilovolt values and proper gap spacings (when the test levels are specified by gaps) for impulse testing power transformers having standard insulation levels and where the specified wave front is 1,000 kilovolts per microsecond and of negative polarity.

If the time of gap flashover is 0.6-microsecond (determined by cut-and-try method) the impulse kilovolts by curve *A*, figure 10, should be 1.44 times the long (chopped) wave (chopped) test kilovolts.

Table II of article "Insulation Strength of Transformers"[9] gives the chopped wave test as 405 kv for a transformer of 69-kv rating.

Therefore, the front-of-wave test voltage for a 69-kv transformer should be $405 \times 1.44 = 583$ kv which flashes over in 0.583 microsecond (or approximately 0.6 micro-

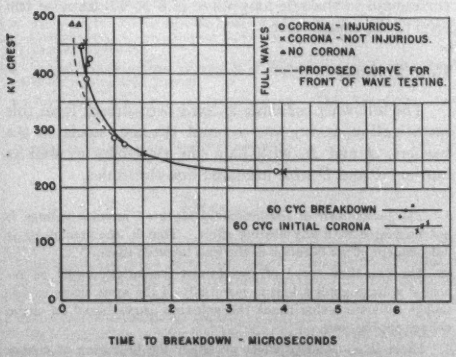


Figure 8. Volt-time curves of transformer insulations, impulse life tests on 0.64 inch barrier C, positive waves, 1.5x40 for full-wave tests

second) at 1,000 kilovolts per microsecond. If the tests were specified by rod-gap spacing, the lengths of gap (by curves in figure 9) for 583 kilovolts should be approximately 11 inches (by curve *A*) for an average wave front of 1,000 kilovolts per microsecond and approximately 13 inches (by curve *B*) for an effective wave front of 1,000 kilovolts per microsecond.

It should be kept in mind that if the average rate of rise (line *A*, figure 9) is 1,000 kilovolts per microsecond, the effective rate of rise will be more than 1,000 kilovolts per microsecond—in the order of 1,200 to 1,500 kilovolts per microsecond, depending on the bend-over of the wave. It is for this reason that the gap spacing should be less when using average rate of rise.

In a similar manner the test-gap spacings were determined for 92-, 115-, and 138-kv transformers having standard insulation levels. The results are given in table III.

The above shows that the test-gap spacing for front-of-wave testing will depend not only upon the insulation level but also upon the method of defining the rate of voltage rise. It should be kept in mind that while the gap spacings are different in the last two columns, they represent the same flashover kv values. Further laboratory data are needed on 1,000 kilovolts per microsecond flashover of rod gaps below ten inch and above 30 inch spacings before working out gap spacings for other circuit kilovolt ratings, especially ratings above 138 kv.

Furthermore, as the curves in figure 9 are based on limited data from only one laboratory, the spacings shown in table III are subject to change when final volt-time curves for rod gaps are agreed upon by the EEI-NEMA subcommittee on correlation of laboratory data. The main purpose in presenting this data is to show the proper method of deriving gap spacings for front-of-wave testing.

Table III. Rod Gap Spacings for Front-of-Wave Tests of Power Transformers

				Front-of-Negative-Wave Tests		
	AIEE Recom. Chopped Wave			Approx. Time	Gap Spacing—Inches for 1,000 Kv per μ sec	
Rated Circuit Kv	Kv	Multiplying Factor	Kv	to F. O. μ sec	Eff. Front	Avg. Front
69	405	× 1.44 =	583	0.6	13″	11″
92	515	× 1.38 =	710	0.7	18	15.5
115	625	× 1.33 =	830	0.83	23.5	20
138	750	× 1.27 =	950	0.95	30.0	25.5

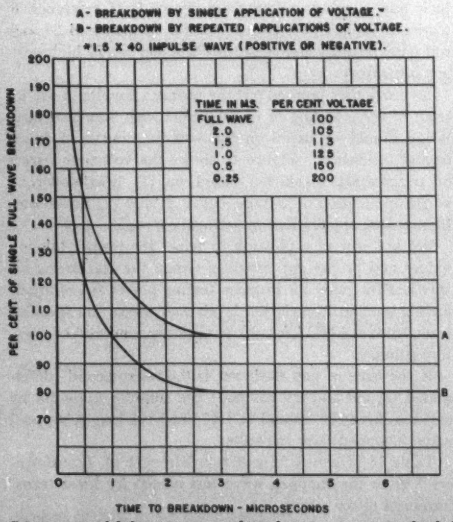


Figure 10. Volt-time curves of insulation, consisting of solid insulation and oil in series (simulating major insulation in a power transformer)

Protecting Old Power Transformers Against Steep-Front Waves by Rod Gaps

It should be realized that the bend-up of volt-time curves of insulation shown in figure 10 does not necessarily apply to old unshielded transformers where the impulse stresses between turns and between coils are much higher for steep-front waves than for long waves of the same applied kilovolts. This is true mostly for the higher-voltage ratings where the windings were not shielded to prevent excessive voltage stresses between turns and coils when subjected to steep waves.

In other words, while figure 10 shows the shape of volt-time curves for the major insulation for both old and new transformers it does not necessarily represent the shape of the volt-time curve for turn to turn and coil to coil insulation for all transformers in service. In some cases of old transformers it may not be possible to permit any turn-up in the volt-time curve. It should be understood, however, that this reduced turn-up is not due in any way to the characteristics of the insulation itself but rather to the increased turn and coil voltage stresses (as expressed by percentage of the applied wave) resulting from steep waves. In all cases the flat part of the curve, figure 10, should correspond to the safe long wave (1.5 × 40) impulse test level of the transformer.

Conclusions

The following conclusions have been drawn from this investigation, taking into account the tests made on the barriers, *A* and *B*, with bare line electrodes as well as barriers *C* and *D* with insulated line electrodes.

1. The breakdown of insulation by repeated impulse voltage is not associated with any heating effect. That is, the breakdown is independent of the duration of the wait between shots.

2. The volt-time curve of transformer insulations based on repeated voltage applications is essentially of the same shape as (although of lower value than) the volt-time curve based on single voltage applications.

3. There is no polarity effect on either the beginning of corona or the breakdown of insulation. (NOTE: If any polarity effect exists for insulation it should have shown up in these tests made with a small coil as one electrode and a plane 36 inches by 46 inches as the other electrode.)

4. Streamer corona damages insulation, while glow or brush discharge corona under conditions within the limits of this investigation (impulse of short time duration compared to 60 cycles) may not cause any measurable damage. There is no definite voltage at which corona of the brush discharge type first occurs on a given barrier.

5. The corona band on the edges (either inside or outside) of the coils with turn insulation was generally wider on full waves than on steep-front waves. In some cases on life tests there was no visible corona on the coil with steep waves until puncture occurred. The kv at which corona appeared on different coils, however, varied to some extent for steep waves.

6. With bare line (generator-side) electrodes the ratio between the repeated shot injurious corona and the repeated shot breakdown (reached by graduated voltage steps of 100 shots at each step) varies over quite a range. In some cases the repeated shot injurious corona was as low as 65 per cent of the single shot breakdown while the breakdown with 100 or more shots was as high as 90 per cent of the single-shot breakdown.

7. With an insulated line electrode the injurious corona on full waves generally ranges from approximately 75 per cent to 85 per cent of the single shot breakdown although in some few cases it was as high as 90 per cent. While the repeated-shot strength (100 shots or more) may be higher than the injurious corona point, the volt-time curves of repeated shot strengths of insulation should be based on the injurious corona level since failure would eventually take place if enough shots were applied. A safe over-all average value to use appears to be about 80 per cent.

8. When front-of-wave testing of transformers is desired it is preferable that the test be specified by kilovolts and time—the values being based on the volt-time curve of transformer insulation, figure 10. If the larger gap spacings (last two columns of Table III) are specified the effective rate of rise should be used.

References

1. Co-ordination of Insulation, V. M. Montsinger and others. AIEE Transactions, volume 52, June 1933, pages 417–27.

2. Breakdown Curve for Insulation, V. M. Montsinger. Electrical Engineering, volume 54, December 1935, page 1300.

3. Factors Influencing the Insulation Co-ordination of Transformers, F. J. Vogel. AIEE Transactions, volume 52, June 1932, pages 411–16.

4. Factors Influencing the Insulation Co-ordination of Transformers —Part II, P. L. Bellaschi and F. J. Vogel. Electrical Engineering, volume 53, June 1934, pages 870–6. Discussion, volume, 53, October 1934, pages 1401–7.

5. Multiple Lightning Strokes, K. B. McEachron. Electrical Engineering, December 1934.

6. Effects of Time and Frequency on Insulation Test of Transformers, V. M. Montsinger. AIEE Transactions, volume 43, pages 337–47, 1924.

7. Progress Report on Impulse Testing of Commercial Transformers, F. J. Vogel and V. M. Montsinger. AIEE Transactions, June 1933, volume 52, number 2, page 409.

8. Short-Time Sparkover of Gaps, J. H. Hagenguth. Electrical Engineering, January 1937, page 67.

9. Insulation Strength of Transformers. AIEE Transformer Subcommittee. Electrical Engineering, June 1937.

10. Power Transformers With Concentric Windings, K. K. Paluev. Electrical Engineering, June 1936, page 649.

Discussion

J. E. Clem (General Electric Company, Schenectady, N. Y.): Mr. Montsinger has given us another paper which should be useful in improving the design of transformers in regard to their lightning-strength characteristics. This discussion will suggest an application of the material in the paper.

It is interesting to note that the data in table I can be closely approximated by a simple empirical expression as follows:

$$R = 0.75 \times \frac{0.5}{t^{\frac{1}{11}}}$$

Table I. Impulse Volt-Time Values by Test and Equation

Time t to Breakdown (Microseconds)	Ratio R of Breakdown Voltage at Time t to Full-Wave Breakdown Voltage	
	Paper	Equation
0.25	2.00	2.010
0.5	1.50	1.544
1.0	1.25	1.250
1.5	1.13	1.132
2.0	1.05	1.065
3.0	1.00	0.990

R = ratio of voltage at breakdown to full-wave breakdown voltage.

t = time to breakdown in microseconds.

See table I of this discussion for comparison of test and calculated values.

The average steepness to the point of cut-off of the wave front of lightning as it appears on transmission lines is less for the lower-voltage circuits than for the higher-voltage circuits. Measured values of kilovolts per microsecond range from 40 to 2,000 with only a few exceeding 500 volts per microsecond. These facts should be considered in any proposals for wave-front testing of transformers.

When the present Institute Impulse Test Code was first prepared it was recognized that changes or additions probably would be necessary, as the knowledge of the nature of lightning increased and as experience in testing developed. The basic reason for setting up impulse tests is to establish definite insulation values which may be demonstrated by test and which may serve as a measure of the protection which must be provided when the transformer is in service.

It has long been recognized that the main source of damaging overvoltages is lightning and accordingly the impulse test should be of such a nature that the results can be correlated with operating conditions. The present impulse test consists of two applications of a chopped wave followed by one application of a full wave. This test simulates to a certain degree traveling waves and waves chopped some distance from the station. However, the Institute should consider some test which better demonstrates the insulation level of transformers for conditions corresponding to a nearby direct stroke which imposes a very rapidly rising voltage.

There has been a demand for tests of this latter nature, in which a wave of a specified rate of rise and magnitude is applied to the transformer. In order that there be a common basis for specifying the test requirements and making the tests I am proposing that the Institute immediately begin the preparation of standards for front-of-wave testing of transformers.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): Mr. Montsinger has presented a paper setting forth the results of

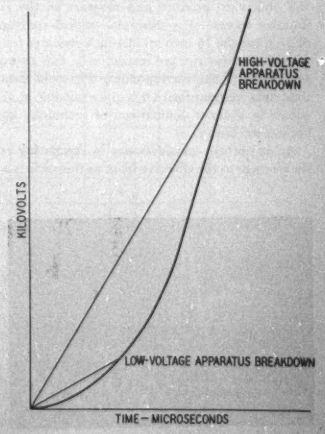


Figure 1. Effect of wave shape on rate of rise from zero volts

an investigation in the high-voltage engineering laboratory on transformer insulation under front-of-the-wave conditions. It must not be inferred, however, that information is available as yet indicating how steep the waves may be expected to be in practice. A figure of 1,000 kilovolts per microsecond has been mentioned and used at times, but it is not known how often such a wave front would be measured in service. Most of the data on wave front comes from the work of Norinder,[1] but these results must be used with caution on account of the possibility of error.

Furthermore, although the author is discussing only power-transformer insulation, yet I think it is wise to point out that rates of rise, to be expected for low-voltage circuits, may well be appreciably less than for high-voltage equipment. This situation is illustrated in figure 1, which shows the probable shape of a direct stroke of lightning initiated by a downward leader. McEachron[2] and McMorris have shown that this wave shape would be expected as the result of the motion of propagation of the downward leader carrying a charge. The only oscillogram[2] measuring the potential of a direct stroke of lightning close by also indicates the same kind of front. I have no doubt but that many kinds of fronts are possible, but figure 1 indicates that the same rate of rise should not be applied to low-voltage transformers as is applied to the high-voltage transformer, on account of the lower insulation level.

Attention is being directed toward the securing of wave-shape data, but it cannot be obtained quickly, even after means and methods are devised for making a sufficient number of measurements to be significant. This all states that much care must be taken in undertaking any program of front-of-wave testing, and low-voltage transformers will require in all probability lower rates of voltage rise than high voltage transformers.

References

1. Lightning Currents and Their Variations, **Harald Norinder.** *Jour.* of Franklin Institute, volume 220, number 1, July 1935, pages 89–92.

2. The Lightning Stroke: Mechanism of Discharge, **K. B. McEachron** and **W. A. McMorris,** *General Electric Rev.*, October 1936, pages 487–96.

3. Lightning Investigation, **Edgar Bell** and **A. L. Price.** AIEE Transactions, volume 50, number 3, September 1931, pages 1101–10.

P. L. Bellaschi (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Mr. Montsinger has presented a valuable contribution on the co-ordination of transformer insulation to steep-front impulse waves. Similar extensive investigations at the Sharon high-voltage laboratory have established that what has been accomplished for the distribution transformer in the way of self-protection against lightning strokes[1] appears feasible and economical also for the modern power transformer.

One of the factors which has contributed to this development is the ability to produce and measure in the laboratory steep-front impulse waves. For example, typical rod-gap values obtained at Sharon for the 15-inch and 24-inch spacings for a 1,000 kv per microsecond effective rise are respectively, 620 kv and 830 kv. The good agreement of the corresponding Pittsfield data in figure 9 suggests that some standardization is quite possible at this date. In so doing naturally a closer comparison of technique and test methods may become necessary.

An important consideration in comparing results is the ratio of the average to the effective front as this ratio is a measure of the shape

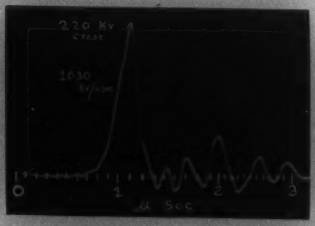


Figure 2. Commercial impulse test on 13.8-kv transformer. This oscillogram also illustrates the impulse voltage applied repeatedly to a 13.8-kv transformer model

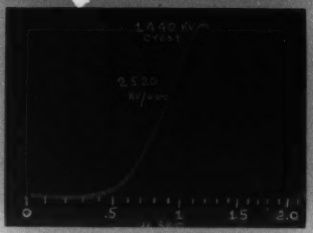


Figure 3. Impulse voltage applied to 138-kv transformer model

of the wave and of the rounding at the chopped crest. The experience at Sharon in testing many barriers and a number of transformers has shown that this ratio for the various conditions hereto encountered has ranged from 0.70 to practically 1.00. On the average the ratio is in the order of 0.85 which indicates that the wave in general is quite sharp at the crest. Locating the rod gap right at the bushing of the apparatus tested and operating the impulse generator as high up in the voltage setting as possible with respect to the chopped test voltage should contribute to a front in which the ratio of average to effective is high, such as the oscillograms of the transformer model tests given in figures 2 and 3 show.

The conclusion Mr. Montsinger arrives at in table III where quite different rod gap values are set up for each of the two methods of defining the front, is difficult to understand. The insulation characteristic in figure 10 is a volt-time curve, therefore the rod-gap schedule under the average front column appears as the logical one. The appreciable difference in the gap values for the average and the effective front columns is hardly to be expected for the reason that the insulation characteristic and the rod gap characteristic each vary in the same direction and about the same relative amount. For example, increasing or decreasing the basis of the rate of rise in table III either to 1,500 kv per microsecond or 750 kv per microsecond (according to the Sharon rod-gap data) would indicate substantially the same schedule of rod gaps. In other words by virtue of the close similarity in the insulation and rod-gap characteristics over a certain range of the time once the correct schedule of gaps has been established co-ordination for the shorter or longer impulses should be expected. It is clear, too, on this score that the method of testing would be rather immaterial. On the other hand there are certain advantages inherent in the effective method, as better control in testing. The effective front responds more directly to generator setting and is accordingly subject to somewhat better control.

Mr. Montsinger indicates that reason for a 1,000 kv per microsecond rate of rise as a basis for testing transformers. From the extensive experience of apparatus in the field that has given adequate service and judging the relative ability of this old apparatus in withstanding the steep-impulse tests that have been applied to modern transformers, the 1,000 kv per microsecond appears in general quite justified. The measurements taken at the end of the 220 kv Wallenpaupack-Siegfried line several years ago[3] indicated front steepnesses lower than 1,000 kv per microsecond. On the other hand an oscillograph record[2] measured within a few hundred feet of a stroke to this same line shows a rate of rise in the order of 1,500 to 2,000 kv per microsecond. Had there been a substation close by, the front at the apparatus quite likely would have suffered some reduction due to the station capacitance. There have been indications of steeper fronts appearing on wood-pole lines with no ground wire as the result of direct strokes to the line conductors and the high insulation level of the line. A rate of rise apparently as high as 5,000 kv per microsecond seems to have been measured.[4]

While abroad this past summer, the writer had the occasion to discuss with various investigators the problem of the probable rate of rise of lightning. One of the more important field studies in this connection has been the investigation in Switzerland under the direction of Doctor K. Berger.[5] Oscillograph records taken at one important substation which connects to a 150-kv line and where an 80-kv line terminates, have not to this day indicated fronts up to 1,000 kv per microsecond, though direct strokes on the lines have rather frequently occurred. In an interesting analysis prepared for

IEC,[6] Doctor Berger calls attention to the possibility of impulse voltages attaining a rate of rise as high as 5,000 kv per microsecond—figure representing the upper limit, such as in the case of a severe direct stroke to the line conductor. These impulses attenuate rapidly and as stated above the station capacitance would contribute also in reducing the steepness. For lines properly shielded with ground wires and having reasonably low tower-footing resistance, even in the case of a back flash onto the line a rate of rise steeper than 1,000 kv per microsecond does not appear probable.[6] With due weight to the investigations and experiences on lightning-stroke phenomena both here and abroad, in my opinion the 1,000 kv per microsecond rate of rise for testing transformers is as sound a figure as our present knowledge will permit.

The tests on distribution and power transformers with steep impulses such as shown in figures 2 and 3 mark quite a step in the progress of insulation co-ordination. In view of the greater difficulty steep-front impulse testing should however, be considered more in the nature of a type test. Somewhat greater tolerance should, for the present at least, be recognized in making such tests as compared to the standard AIEE tests on full wave and waves chopped on the tail.[7]

References

1. Direct-Stroke Protection of Distribution Transformers, H. V. Putman. *Electric Journal*, February 1937.
2. AIEE Lightning Reference Book, page 790.
3. AIEE Lightning Reference Book, page 697.
4. AIEE Lightning Reference Book, page 873.
5. The Results of Lightning Measurements Made in the Years 1934–35, K. Berger. *Bull. SEV*, November 6, 1936.
6. The Wave-Front Steepness of Impulses Applied to Transmission Line Insulators as a Consequence of Direct Lightning Strokes. Report to the IEC Committee for Impulse Testing of January 1936.
7. Insulation Strength of Transformers, AIEE Transformer Subcommittee. Electrical Engineering, June 1937.

L. H. Hill (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): Mr. Montsinger's paper is worthy of considerable interest. When it is realized that the data in his paper represent approximately 10,600 impulse tests, the difficulty of obtaining reliable data relating to impulse phenomena may be better appreciated.

After considering the data submitted by Mr. Montsinger, a few questions arise. These refer to figures 6, 7, and 8 in the advance copy of the paper. It will be noted the ordinates of the curves are labeled "kv crest." From this, one assumes the 60-cycle values are also in crest kilovolts.

Consider, first, figure 6, which represents an insulating barrier for a 15-kv class transformer. The AIEE low-frequency dielectric test for this class is 34 kv effective, or 48 kv crest. Assuming the plotted 60-cycle corona and breakdown values as crest kilovolts, it is found the factor of safety or ratio of 60-cycle initial corona to low frequency dielectric test is 137/48 = 2.85. This appears to be a reasonable factor of safety.

Upon going to figure 7 and the 92-kv class of insulating barrier, a different picture develops. For this class the low frequency dielectric test is 185 kv effective, equivalent to 261.2 kv crest. Mr. Montsinger's data give the 60-cycle initial corona point as 275 kv, which gives a factor of safety of 275/261.2 = 1.05, a value which seems too close for 100 per cent assurance against damaging the insulation even before the transformer has left the manufacturer's shops.

Because of the wide spread between impulse injurious corona and one-shot breakdown, it is of course essential to design transformers using the injurious corona as the impulse strength of the transformer. If encroachment is made into the region above the injurious corona level, damage may be done without knowing it. As the transformer must withstand the crest value of the chopped wave when subjected to an impulse test, it is essential to regard this figure rather than the lower full-wave impulse shot as the one determining the impulse ratio.

Referring to figure 6, the impulse injurious corona level is found to be 240 kv. In accordance with the latest recommendations of the transformer subcommittee, the chopped-wave crest for this class is 130 kv, resulting in a factor of safety of 240/130 = 1.85. For the 92-kv class the impulse injurious corona level is 680 kv, and the chopped-wave crest value is 515 kv, giving a factor of safety of 680/515 = 1.32.

No mention is made of the method used to determine the point of initial corona under impulse test. Injurious corona can be detected by markings, but initial corona supposedly is non-injurious to the material and would leave no mark; hence an outline of the method used would be of interest.

J. H. Hagenguth (General Electric Company, Pittsfield, Mass.): Mr. Montsinger clearly points out the necessity of differentiation between an impulse test made with a 1.5 x 40 wave and a wave having a rate of rise of say, 1,000 kv per microsecond. Whether or not steep-front tests are desirable and what rate of rise should be used for transformers of different voltage classes has to be decided on consideration of actual lightning fronts (information of which is meager) and on tests such as described in the paper. If practical, these tests should be supplemented by steep-front tests to establish volt-time curves for turn, coil, and major insulation.

Several front-of-wave tests have been made on a commercial basis by the laboratory with which I am connected. The results of these tests were satisfactory from the point of view that failure did not occur. The kilovolt ratings of the windings tested, and the impulse voltages applied are given in table I of this discussion. At present, no method of definitely detecting small failures, such as turn-to-turn failure or coil-to-coil failure is available. My experience has shown that normal-frequency voltage applied to experimental transformers has never resulted in follow currents although failure due to impulse was detected by other methods. This type of failure, however, is progressive and finally will cause a normal frequency short circuit, when the failure path is sufficiently carbonized. In transformers with uniform voltage distribution the front-of-wave test limits of figure 10 of the paper apply probably for the transformer as a unit

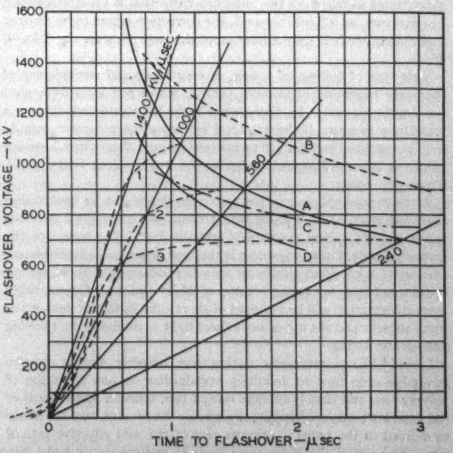


Figure 4. Flashover voltages of a 30-inch rod gap on the front of the wave, negative polarity, for 1,000 kv per microsecond rate of rise

Wave 1—On the basis of average rate of rise
Waves 2 and 3—On the basis of effective rate of rise
Curve *A*—Volt-time curve for 30-inch rod gap obtained with 1.5 × 40 wave
Curve *B*—Volt-time curve for 30-inch rod gap obtained with practically straight-line voltage rise, flashover on the rising front
Curve *C*—Volt-time curve of transformer insulation, 138-kv voltage class
Curve *D*—Volt-time curve of 25.5-inch rod gap obtained with 1.5 × 40 wave
Straight lines indicate rate of voltage rise in kilovolts per microsecond

since turn insulation exhibits characteristics similar to the sample barriers tested. Transformers with poor initial voltage distribution would be subjected to considerably higher internal stresses during the steep front test than during the present standard AIEE. A point of some concern is the method of testing with steep-fronted waves.

1. Voltage Measurement

At short times to flashover the flashover voltage measured by different laboratories for a given spacing and time to flashover differs by 20 per cent and more. This is mostly due to the use of different types of voltage dividers. It appears, therefore, doubtful, that a test standard could be devised on the basis of flashover voltage of a rod gap, at present, because this would definitely mean that transformers of different manufacturers were receiving tests of different severity. Similarly, of course, it seems quite impossible to use the rate of rise of the wave as a standard measure, since this in turn would imply a more exact knowledge of the actual flashover voltage.

2. Rod-Gap Method (Temporary Expedient)

For the reasons stated above, rate of rise does not appear as a satisfactory yardstick for impulse testing at present. However, rod-gap spacings can be specified for the various voltage classes of transformers which have been found by experience to be capable of limiting the applied voltage to a maximum voltage value. The spacing alone would not suffice to assure application of similar voltage waves to a transformer by different manufacturers (as will be shown later) and it is necessary to specify the maximum time to flashover to be measured by a cathode-ray oscillograph. Irrespective of the type of divider used, the time to flashover will be measured with almost equal accuracy and a test specification of this type should, therefore, yield uniform test results by all manufacturers. The principal objection against the use of rod gaps in the present standard was that its flashover voltage varies greatly with humidity. The humidity effect is less objectionable for front-of-wave tests since at short times to flashover the humidity correction is greatly reduced. For instance, at 0.5 microsecond, the correction seems to be zero, at 2 microseconds it is only a fraction of the correction for the 1.5 x 40 wave.

This type of testing, of course, is very crude and reminds one of the early beginning of impulse testing, where rod gaps were used for similar reasons. It, therefore, should be considered only as a transitory measure to be replaced by volt-time measurements as soon as standardized voltage measurements and short-time flashover values of gaps and insulators are agreed upon by the EEI-NEMA laboratory group.

At that time sphere-gap spacings should perhaps be used rather than rod gaps, although this would mean the use of two different types of gaps during a complete impulse test. For waves of the present standard test requiring a chopped wave with flashover occurring at a specified minimum time the sphere gap would be unsuitable, at least for voltage classes of 25 kv and up. Considerably more information will be required of short-time flashover voltages of small spheres and the use of ultraviolet light to diminish the time lag and erratic arcing.

I would like to emphasize at this time, however, that it appears advisable even now to definitely standardize on one definition of voltage rise, and that is average rate of rise, whether sphere gaps or rod gaps are used for chopping the wave. At present, two are in use as defined in the paper: average rate of rise and effective rate of rise. The use of the latter term leads to confusion and lacks precision as will be explained by the use of figure 4 of the discussion. For illustrative purposes this figure has been drawn for a 30-inch rod gap. Curve *A* represents the volt-time curve of a 30-inch rod (as recommended for front-of-wave testing for 138 kv rated circuit voltage) obtained with a 1.5 x 40 wave. Curve *B* represents the volt-time curve of a 30-inch rod gap obtained with waves rising at substantially a uniform rate of rise. Curve *C* represents the safe voltage limits for power transformers of the 138-kv voltage class. Curves *A*, *B*, and *C* were obtained using the same methods of measurement and are, therefore, directly comparable. Superimposed on these curves are straight lines representing different rates of rise. The question of average and effective rate of rise would be irrelevant if the wave fronts applied to the test piece were straight lines, because then the voltage and time to flashover would be the same using either definition. However, waves usually obtained are of the form shown by curves 1, 2, and 3. Curves 2 and 3 represent waves, both of which have an effective rate of rise of 1,000 kv per microsecond. The straight line represents another front at 1,000 kv per microsecond and, therefore, the following values of flashover voltage and time to flashover could be obtained for waves of the same rate of rise on the front.

This table, I believe, shows clearly that the effective rate of rise is too loose a term and cannot be used as a standard of measurement,

Table II

Wave	Flashover Voltage	Time	Per Cent Kilovolts
1	1,070	1.07	100
2	900	1.6	84
3	700	2.87	65.0

especially since it can lead to a condition where steep-front waves of the required rate of rise are applied, but the amplitude is decreased by making the time to flashover long. For instance, the flashover voltage of curve 3 of figure 4 (this discussion) would actually be lower than the specified chopped wave voltage of the present standard test with 1.5x40 wave.

On the other hand, the use of average rate of rise establishes definite limits. For instance, curve 1, figure 4 (this discussion) represents a typical wave which would be applied during a test specified by average rate of rise of 1,000 kv per microsecond. The flashover voltage with this definition cannot be made to be materially lower than, 1,070 kv but rather can be increased by straightening out the wave front to reach a possible maximum of 1,240 kv. In this case, therefore, the bend over of wave front is entirely beneficial to the transformer as far as the amplitude of the voltage is concerned and yet the flashover voltage cannot be lowered materially without obtaining too low a rate of rise, i.e., if the kilovolt value were reduced to 1,000 kv (flashover at 1.26 microseconds) the rate of rise would be reduced to 800 kv per microsecond which would be too low to conform with specifications.

A further advantage of the use of average rate of rise is that it can be obtained from any volt-time curve by simply dividing the flashover voltage by the time to flashover, while the use of effective rate of rise requires entirely separate curves which will be a function of the bend over of the curve as illustrated by curves 2 and 3, figure 4 (this discussion). For instance, curve *B* of figure 9 of the paper applies only to one particular wave front used. Any number of such curves could be drawn, the highest one would coincide with curve *A* while curves with flashover voltages lower than *B* would be entirely possible.

It appears, therefore, necessary that in the final standard for front-of-wave testing, crest voltage and time to flashover or crest voltage and average rate of rise be specified and that the use of effective rate of rise be discontinued.

Concerning the rod-gap spacings to be used at present for front-of-wave tests, figure 4 (this discussion) shows that if average rate of rise is used a rod gap spacing of 25.5 inches (curve *D*, figure 4, this discussion) is required to limit the flashover voltage to 950 kv. This checks values given in table III of the paper. If a rod-gap spacing of 30 inches is used as shown in the paper for effective rate of rise, the flashover voltage should be limited to about 755 kv in order not to exceed the safe limits of the transformer. The time to flashover in this case would be approximately 2.4 microseconds. This test, therefore, would, practically speaking, be exactly the same as the chopped-wave test of the present Impulse Test Standards. Therefore, if the gap spacing of 30 inches is used, either the safe insulation

limits are exceeded by up to 25 per cent or if the voltage is kept below the safe limits of the transformer, the value of the test is doubtful, since the only difference from the present chopped wave is the steeper front.

F. J. Vogel (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Mr. Montsinger has made a real contribution in furnishing data on the strength of insulation under oil. Such tests as those described are indeed difficult and expensive to make. By increasing our knowledge of the behavior of materials, we are provided on the one hand with information necessary to determine what is possible, and on the other hand how to accomplish these possibilities with reasonable factors of safety in actual designs.

When data are furnished, it is usually possible to draw many diverse conclusions from it. It is often dangerous to draw conclusions from another's data but nevertheless there are certain interpretations of Mr. Montsinger's tests which are of great interest and it seems to me that they should be noted.

Barrier *C* is indeed an approximation of 15-kv transformer major insulation, except for the extension of the barrier beyond the coil. It is my impression that in actual transformers, the extension is of

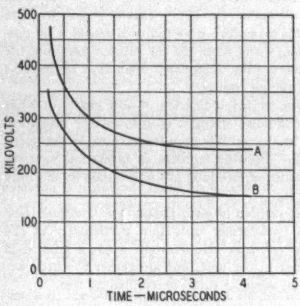


Figure 5

A—Data for barrier *C*, 13.8-kv insulation, Mr. Montsinger's paper "Co-ordination of Power Transformers for Steep-Front Impulse Waves," figure 6

B—Data for five-and-three-quarters-inch rod gap, negative waves

the order of one or two inches for the 15-kv class; it is believed that this extension is not generally sufficient to result in puncture, but that the insulation would fail by creeping around the barrier. In Mr. Montsinger's paper this extension was 13 or 14 inches, sufficient to result in a puncture of the barrier *C* in the tests. However, taking the full-wave value of 240 kv as correct for 15-kv insulation, it is possible to show certain relationships. My figure 5 shows time-voltage values for the five and three-fourths inch gap as determined in Sharon, compared directly with Mr. Montsinger's curve figure 6. There is a margin of 30 per cent between these curves, even at extremely short times. This curve indicates to the writer that it might be possible economically to make transformers of this type of construction completely co-ordinated. Barrier *C* is typical, depending upon the manufacture, of transformers insulations up to 46 kv, except for the amount of extension. The barrier thickness will, of course, vary up to one or one and one-half inches or more.

Barrier *D* is described as typical of approximately 92-kv class insulation, tested at 185 kv root-mean-square. It is to be noted that 275 kv crest is 194 kv root-mean-square; 275 kv crest at 60 cycles is the maximum voltage which barrier *D* will withstand without injurious corona. If the insulation in an actual transformer, is not to be injured on test at 185 kv root-mean-square, there must be a margin in the design. According to table II, row 3, the insulation would withstand without corona, full waves of 680 times 185 divided by 194 or 650 kv, with the designer's margin. One might reduce this value somewhat further by taking the lowest value for injurious corona instead of the average value which would reduce the figure to 590 kv. The data on figure 7 may then be redrawn as shown in figure 6 to be representative of 92-kv class insulation. For comparison, a curve given by Mr. Hagenguth for a 20-inch gap, published in the January issue of ELECTRICAL ENGINEERING, is also shown. This would indicate that a 20-inch gap could protect a 92-kv transformer against extremely high voltages for extremely short times, even for direct strokes of lightning. It is to be noted that barrier *D* is similar to the insulation generally used in the 69-kv class and above and similar relationships should hold. This would tend to confirm Mr. Montsinger's opinion that it is impractical to build completely co-ordinated transformers when a gap alone is to be relied upon.

The results of tests on barrier *D* only confirm my opinion further that higher impulse strengths should be obtained than those at present standardized for the higher voltage classes. Data published by the writer has been chiefly on the basis of interleaved insulation similar to barrier *D* and typical of actual transformer insulation. Mr. Montsinger's data also show 2.2 to be a fairly average value for the ratio between impulse and 60-cycle breakdown and corona voltages for interleaved insulation. Under these circumstances, it is difficult to see why a 570 kv is not a more reasonable value for impulse-testing 92 kv insulation than the present AIEE subcommittee recommendations of 515 kv. This is particularly true when the higher value is desirable from the standpoint of obtaining protection under the worst conditions. Whether Mr. Montsinger is correct or not in stating that there is no definite impulse ratio that applies to all voltage ratings of transformers, he has at least furnished confirming evidence that ratios of 2.2 or higher can be obtained with some constructions. Further it would seem that the impulse strength is really the important one from the service standpoint and that the 60-cycle test is relatively unimportant. If present impulse test values are retained, it would seem that the 60-cycle test values might be abandoned or at least reduced in order to provide a greater degree of flexibility for the designer.

It is difficult to see how it is possible to change the gap values as much as Mr. Montsinger states when using effective values as compared with average values. Referring to figure 7 in my discussion, a sample oscillogram is shown and the two methods of interpretation described by Mr. Montsinger are illustrated. These data can be plotted on the curve using either average or effective times. This curve shows how a higher voltage will be obtained for a given rate of voltage rise using the average value. Assuming that these curves apply for a rod gap, is there any reason to believe that similar curves do not apply to transformer insulation? If so, figure 8 shows what might be obtained for transformer insulation. Mr. Montsinger, in his method of deriving gap lengths, is really comparing volt-time curves for gaps with similar curves for transformer insulation. If average values are used to compare results, it is seen that we obtain approximately the same length as obtained by Mr. Montsinger. If we compare the effective values for the rod gap with the average rate-of-rise data for the insulation, we find that the gap can apparently be increased. The writer does not believe this to be actually the case. It is suggested that to prove this, it might be desirable to test insulation, protected by a rod gap, with different shapes of waves to see if there is really a difference, as Mr. Montsinger believes. It would be desirable for another reason also. Those customers desiring tests with gaps and steep-wave

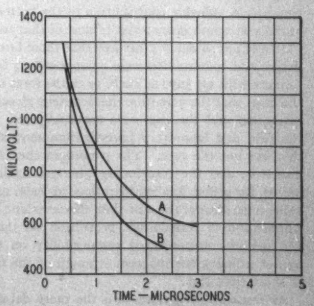


Figure 6

A—Data for barrier reduced to 92-kv class, Mr. Montsinger's paper "Co-ordination of Power Transformers for Steep-Front Impulse Waves," figure 7

B—Data from maximum values for 20-inch rod gap (positive or negative), Mr. J. H. Hagenguth's paper "Short-Time Sparkover of Gaps," figure 14, ELECTRICAL ENGINEERING January 193

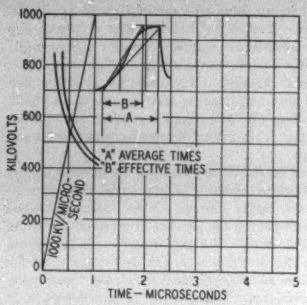


Figure 7. Data for 11-inch rod gap, showing effect of method of scaling oscillogram on time-voltage curve

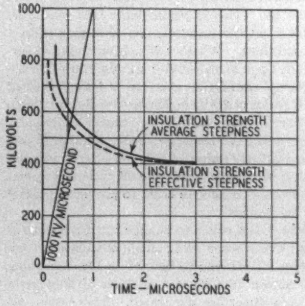


Figure 8. Data for 69-kv transformer insulation, from proposed method given in Mr. Montsinger's paper

fronts intend to use the gap as a protective device. They are not therefore, interested in voltage and time values but only in proof that the co-ordination actually works. Therefore, it is believed that it is desirable to use the gap directly and avoid the use of volt-time curves for this purpose.

There is still another suggestion, that is, that tests on sample transformers under these conditions are desirable. When the test values of 860 and 1,430 kv were proposed for 138- and 230-kv transformers respectively, transformers had been given endurance tests to see that these values could be withstood, and likewise tests with steep-wave-front waves on sample transformers are desirable before values actually withstood can be stated without question.

I. W. Gross (American Gas and Electric Service Corporation, New York, N. Y.) [**Editor's Note:** This discussion covers also "Corona" Voltages of Typical Transformers for Steep-Front Impulse Waves, F. J. Vogel. *EE, Jan. '38, Trans. p. 34–8.*]: These two papers comprise a valuable contribution to the better understanding of the impulse strength of material typical of that used in transformers.

It was not so many years ago that those familiar with transformer design and construction were recommending the protection of transformers with air gaps as such, or in the form of insulator strings, on the basis that the volt-time characteristic strength of the transformer insulation and the gap were essentially the same. Experience in the field and laboratory investigation soon showed definitely that this was not the case. The pendulum then swung in the opposite direction, and the transformer strength against lightning was depicted, for protection considerations at least, as being a fixed voltage value regardless of the volt-time characteristic of the lightning wave. Application of transformer protection on this basis placed heavy and perhaps unwarranted responsibility on the protective device by not utilizing the inherent strength of the transformer insulation at short time lags.

As research progressed into the more detailed characteristics of transformer insulation under impulse stresses, information which formerly had been qualitative became quantitative. We now find in Mr. Montsinger's paper definite suggestions for applying front-of-wave impulse tests at voltages considerably higher than the present full or chopped-wave tests. Such tests should demonstrate in a practical way that the short-time insulation strength which is now supposed to be built into the transformer is actually there. These suggestions, I am sure, will prove extremely valuable in setting up a test procedure for standardizing front-of-wave testing on transformers, a subject the transformer subcommittee has been actively working on for more than a year. Further, I thoroughly agree with Mr. Montsinger that front-of-wave testing be set up on a voltage and time basis which are definite units of insulation measurement rather than by specifying inches of gap, thus leaving the gap as a useful test device to chop the wave on the front, as may be specified.

Both Messrs. Montsinger and Vogel have encountered the same difficulty in carrying on their test work, namely, entrapped air in the insulation which has not received special treatment. The special treatment used by the authors, assembly under oil, vacuum treatment, tapping of the assembled sample to remove this air and thus increase the impulse strength leads directly to the question, why should it not be possible to increase the impulse strength of commercial oil-insulated transformers by admitting oil to the tank while the winding is still under vacuum? This of course leads to the next question: if this procedure were followed would it be possible in the field to change and filter the oil without breaking the vacuum, or without more than temporary reduction of impulse strength resulting from the oil change?

Could the authors give us any indication of how much, or what percentage, increase in impulse strength of transformer insulation it is possible to obtain by this oil filling under vacuum as compared with nonvacuum filling? Possible increase of insulation strength of transformers by a change of oil-filling procedure such as this may well be worth considering.

It is to be hoped the authors of both papers will continue their valuable researches on transformer insulation particularly in the short time region of the volt-time characteristic where a great deal of speculation has existed in the past, but altogether too little actually known to the point where it could be verified by test.

V. M. Montsinger: I believe the reason that Mr. Bellaschi gets a smaller difference in gap spacing for different rates of voltage rise (of, say, 750 to 1,500 kv per microsecond) than the data in my paper indicates, is because the Pittsfield gap volt-time curves probably have higher kilovolt values for short times than his volt-time curves have for the same gap spacing. In other words, the turn-up may be somewhat more. Figure 9 of this discussion shows volt-time curves of a 25-inch rod gap and a transformer winding (same shape as curve in figure 10) having an insulation level for a standard 138-kv circuit. It will be seen that there is quite a difference in their slopes which does not seem to bear out Mr. Bellaschi's expectations that once the correct schedule of gaps has been established, co-ordination for the shorter or longer waves would be established. This question is best answered by citing the results of tests made about five years ago (table III, reference 1) when a one-half inch pad of insulation

Table III

Applied Voltage (Per Cent of Full Wave)	Gap Spacing (Inches)	Kilovolts*	Time (Microseconds)
100	20.5	355	5.5
135	16.5	371	2.0
208	13.7	447	0.9
350	10.5	447	0.8
500**	6.25		0.3 (approx.)

* By sphere gap.
** Zero series resistance in generator circuit.

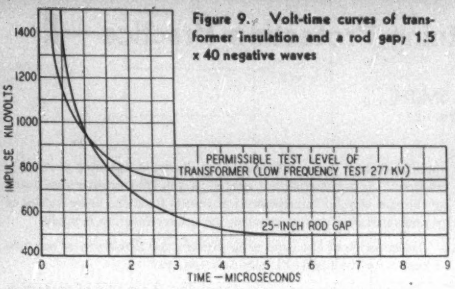


Figure 9. Volt-time curves of transformer insulation and a rod gap, 1.5 x 40 negative waves

(same as barrier *B*) was impulse tested in parallel with a rod gap.

The following tabulation shows to what extent the rod gaps had to be shortened as the wave fronts became steep by applying more and more overvoltages. In each case the gap was adjusted such that its flashover on the wave front was equal to the single-shot breakdown of the pad of insulation.

A study of the oscillograms taken at the time these tests were made shows the following results given in table III.

The above tests show conclusively that to protect even a low-voltage transformer, the gap spacing must be rapidly reduced as the wave fronts become steeper. In other words, any one gap spacing will have an impulse strength equal to the insulation over a very narrow range of time.

Mr. Gross' question about the increase in impulse strength of transformers by admitting oil to the tank with the windings under vacuum, is a difficult question to answer except in a general way. It is the air pockets entrapped in or under the insulation structures and not the air in solution (of the oil) that cause trouble. The seriousness of air pockets in series with oil and solid insulation in a highly stressed electric field can be appreciated when it is remembered that the voltage stresses are in the inverse ratio of their permittivities; i.e., the stress in volts per mil on the air, is approximately 2.2 times the stress in volts per mil on the oil and approximately 4.4 times the stress on the solid, while the dielectric strength of air is in the order of one-fourth to one-sixth that of oil and solid. Any air pockets in series with oil will, therefore, reduce the breakdown of the oil in the order of eight to ten times because when the air becomes ionized and breaks down, the oil breakdown follows. It is, therefore, out of the question to economically design transformers to withstand high impulse voltages with air pockets in the insulation under high stress.

Since the air in solution is not harmful to the dielectric strength of oil (and if the air pockets have been previously removed from the insulation) very little would be gained in the field by changing and filtering the oil under vacuum. Of course, if the oil were drained out of the transformer, air pockets most likely would be introduced when refilling. If the air pockets are adjacent to the oil in circulation under load conditions, they are absorbed in a few hours after the transformer is put in service. Their temporary presence is not harmful if the transformer has been in operation a few hours before being subjected to a high impulse voltage.

Mr. Hagenguth's discussion of average versus effective rate of rise emphasizes the importance of eliminating, if possible, the bend-over of the voltage chopped by the gap. If the bend over is eliminated, and there is reason to believe it can be reduced to a negligible value by using sphere gaps to chop the wave and proper circuit constants, the question of "average rate of rise" versus "effective rate of rise" is done away with, and the testing is simplified. The reason so much space was devoted to this question in the paper was because we are at present being asked to use rod gaps to chop off the wave in front of wave testing of transformers.

Regarding Mr. Hill's discussion, the 60-cycle kilovolt values shown on figures 6, 7, and 8 are the crest values.

As to barrier *C* representing a 92-kv (185-kv low-frequency test) transformer, this barrier represents merely the type of insulation used in a 92-kv transformer. No importance should be attached to its actual kilovolt strength.

The method used in determining the initial corona was by observation—in a dark room. It is true that initial corona may not be injurious. It is more difficult to determine when corona becomes injurious than to detect initial corona. The most satisfactory method of detecting damaging corona, particularly on the coil insulation, was to lower the voltage to the highest value that previously had not shown any corona. If corona appeared it was evident that the coil insulation was damaged. Damage to the pad itself did not occur until after the insulation on the small coil was injured. Injury to the pad (if the test was continued up to this point) did not mean anything. When using bare electrodes injury to the pad had to be determined by removing from the oil and examining it for tracking.

Distribution Transformer Lightning-Protection Practice—II

By L. G. SMITH
FELLOW AIEE

TO DETERMINE the relative effectiveness of various methods of protecting distribution transformers from lightning an annual survey of operating companies was initiated in 1934 by the transmission and distribution committee of the Edison Electric Institute and continued through 1935 and 1936. In 1934 operating data were obtained from 38 companies, in 1935 from 43 companies, and in 1936 from 41 companies. The results for 1934 were presented in a previous paper. This paper presents a summary of the data for the three years and draws conclusions therefrom. It is only by collecting such data from a number of companies for numerous installations for a number of years will conclusive data be obtained so that annual variations in storm frequency and severity will be averaged. It is planned to continue the collection of these data for several years. In the future it is hoped that data for a sufficient number of years will be obtained from each company so that the troubles may be weighted by the isokeraunic level of each territory served.

Conclusions

Based upon the data collected, the following conclusions appear to be justified:

1. In so far as the rate of primary fuses blown the various protection schemes fall into the following relative order of effectiveness with not much choice among the last three named:

   First: The various methods of solid interconnection of which the solid interconnection with tie to case seems the best followed by the conventional solid interconnection and the common primary and secondary neutral schemes.

   Second: The type *SP* transformer.

   Third: The three-point connection.

   Fourth: The standard connection.

   Fifth: The gapped interconnection.

2. In protecting against transformer-winding failures the relative order of merit is not clear due to inconsistencies in the data. However, it is believed that the newer methods of lightning protection are better than the standard connection with the exception that the three-point connection and the gapped interconnection are practically no better.

3. The data indicate that lightning-arrester failure rates are lower for the types of solid interconnection and type *CSP* transformer than for the standard connection.

4. Solid interconnection does not seem to increase the number of meters burned out or troubles on customers' premises.

5. The ground resistance of lightning-arrester grounds is the most important single factor influencing the degree of lightning protection rendered. It is believed that a large part of the improvement noted by the use of solid interconnection results from the lower values of ground resistance that exist when the interconnection is made.

6. Irrespective of the type of protection the trouble rates seem to be higher for the higher distribution voltages.

7. There is no apparent trend of the effect of the type of protection upon the location of transformer-winding failures. On the average 35.2 per cent of the failures involved the primary only, 11.3 per cent involved the secondary only, and 53.5 per cent involved both the primary and secondary.

8. There seems to be a growing tendency to install secondary arresters on customers' premises.

9. It is believed that the higher the fusing schedule, the lower will be rate of primary fuses blown.

10. In the case of all types of protection a higher rate of primary fuses blown exists when the arrester is installed on the transformer side of the fuse.

11. The rates of primary fuses blown per 100 transformers are practically the same irrespective of whether one or two fuses per transformer are used.

12. The practice of grounding transformer tanks is growing.

13. The amount of attention paid to obtaining low resistance of arrester grounds is not as great as the data warrants except for solid interconnection.

Various Methods of Lightning Protection

The various protective schemes considered in this survey may be classified as follows:

1. *Standard connection* (figure 1) in which the lightning-arrester ground is not interconnected with the secondary neutral. In the case of three-phase four-wire systems the ground lead is usually tied

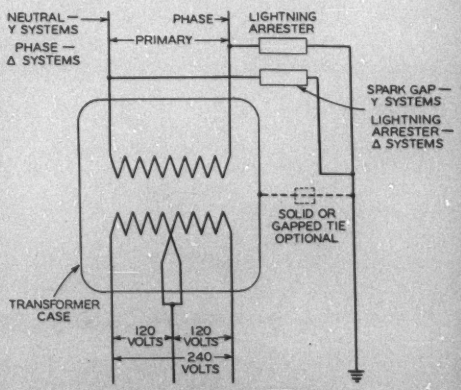


Figure 1. Standard connection

Paper number 37-111, recommended by the AIEE committee on protective devices and presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Manuscript submitted October 20, 1937; made available for preprinting December 21, 1937.

L. G. Smith is assistant to general superintendent, Consolidated Gas, Electric Light and Power Company of Baltimore, Md.

The author wishes to acknowledge the assistance of R. D. Bader, H. C. Miller, and W. J. Witte in summarizing data for the tables, and the co-operation of the various operating companies who supplied operating data.

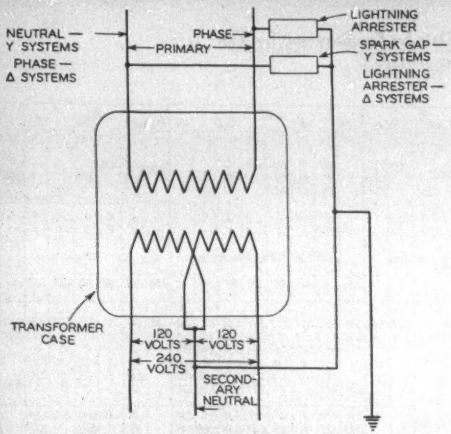


Figure 2. Solid interconnection

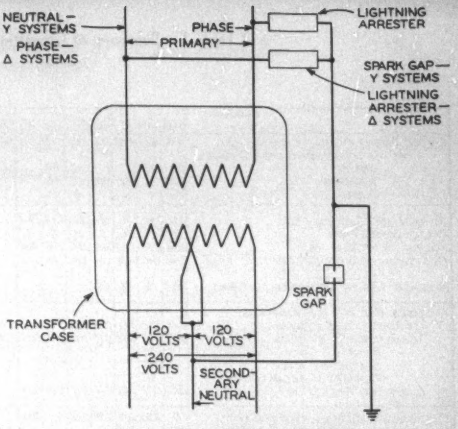


Figure 4. Gapped interconnection

with the primary neutral through a gap. In some cases the transformer tank is grounded.

2. *Various types of interconnection* classified as follows:

(*a*) Solid interconnection (figure 2) in which the arrester ground lead is interconnected with the secondary neutral. The following sub-classification exists:

(1) No tie to the transformer tank (conventional type).

(2) The transformer tank tied solidly to the ground lead as in figure 3.

(3) The transformer tank tied through a gap to the ground lead as shown in figure 3.

(*b*) *Common primary and secondary neutral* (figure 6) which is obviously similar to the solid interconnection. There may be three types of this scheme as follows:

(1) Transformer tank ungrounded.

(2) Transformer tank solidly grounded.

(3) Transformer tank grounded through a gap.

(*c*) *Gapped interconnection* in which the arrester ground is interconnected with the secondary neutral through a gap. This scheme may be divided into the following subclasses:

(1) No tie to the transformer case (figure 4). The conventional type.

(2) The transformer tank tied solidly to the ground lead (figure 5).

(3) The transformer tank tied through a gap to the ground lead (figure 5).

(4) The three point connection (figure 8) in which the ground lead is connected to the tank through a gap and the arrester lead connected solidly to the tank the secondary neutral being connected to the tank through a gap.

3. *Type SP transformer* (figure 7) in which self-clearing spark gaps (deion gaps) are used instead of lightning arresters. It is essentially a gapped interconnection with the tank grounded through a gap and the connections are similar to the three-point scheme.

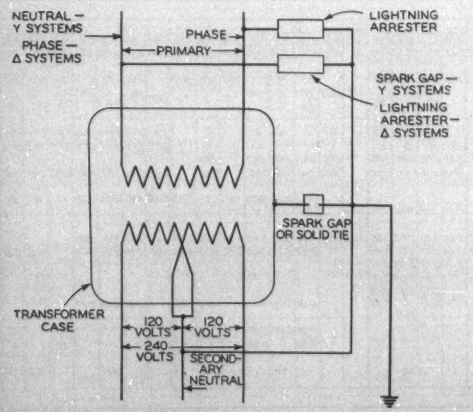


Figure 3. Solid interconnection with tie to transformer case

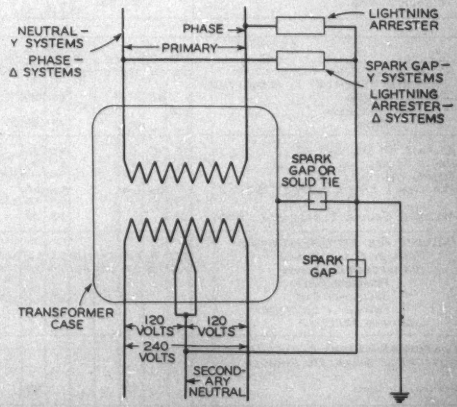


Figure 5. Gapped interconnection with tie to transformer case

Table I. Summary of Operating Data by Company and by Year

Standard Connection—Figure 1

Company	1			2			3				4						6						7
Year	1934	1935	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936		Avg.	1934	1935	1936		Avg.	1934
No. of Installations Reported On	4150	4300	4225	3423	3221	3355		5407	1177	349	6237	4657	5222	450	26	29	2918	1677	1457	3946	536[a]	567[a]	1559	932[a]	37[b]	556	8182	50
Type of Territory By Percentages																												
Urban	100	85	100	100	40	44	100	100			100			50	0	52	100				100	249	100					
Suburban		15			60	48								30	46	3		100				622		100			100	
Rural		0			0	8				100				20	54	45			100			729			100			100
Voltage of System - KV	4	4	4	26.4	24.9	26.4	24.4		2.3	13	23.9			4	6.6	11	2.3 To	13.2			4	4	4	4	4	4		
Phase Connection	Y	Y	Y	Δ	Δ	Δ	Δ		Δ	Y	Δ			Y	Δ	Δ	Δ	&			Y	Y	Y	Y	Y	Y		
Fusing Schedule - %	240	240	240	200	200	200	200																					
Position L.A. With Respect To Fuse	Line	Line	Line	Line	Line	Line	Line		Line	Line	Trans			Line	Line	Line	10% Trans	4.2% Line			All on Trans. Side							
Average Ground Resistance - Ohms	15	15	15	50									25-200	3	40	45	20[a]	40[a]	50[a]		250	250	250	250	250	250	130	90
Failures Per 100 Installations																												
Primary Fuses Blown	13.45	3.95	8.61	0.94	3.72	5.37	3.23	2.14	6.54	17.3	6.42	5.45	3.16	4.89	5.77	8.97	3.55	7.83	30.9	12.62	1.94	1.41	5.16	2.80	5.40	2.34	10.65	10.00
Transformer Winding	0.29	1.05	0.66	0.19	0.69	0.56	0.47	0.96	0.71	0.95	1.28	1.04	0.32	6.22	15.4	17.2	0.56	0.95	2.61	1.31	0.20	0.18	0	1.02	0	0.26	0.62	0
Primary Only		0.88												3.33	3.85	3.45	0.34	0.36	0.96	0.71		0	0	0	0			0
Secondary Only		0.17												1.11	0	3.45	0.07	0.12	0.69	0.30		0	0	0.78	0	0.26		0
Primary & Secondary		0												1.78	11.5	10.3	0.13	0.48	0.96	0.60		0.18	0	0.26	0	0.17		
Lightning Arrester	0.60	2.32	1.48	0.14	0.12	0.03	0.10						0.06	1.78		0	0.27	0.66	2.75	0.82		0	0	0	0	0	3.30		
Customers' Meters Burned Out	0	2.00	1.03	0.39	0.68		0.52						0.11	1.78	0	0	1.21	3.36	11.8	2.94		1.06	4.50	0.78	2.70	1.48		
Customers' Wiring, Etc. Damaged	7.08	0	3.48	0									0.03	3.33	0	0	0.47	0.48	0.48	0.41		0		0.26		0.10		
Grounded Tanks						No				Yes							Above 6.6 KV.						No	No	No			

Company	16				17				18			19				20			21			
Year	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1935	Avg.	1934	1935
No. of Installations Reported On	31233	8980	1700	41933	16777	6735	5531	4351	4151	3711	4449	1817	13	1830	569	3935	1025	2000	2525	4700	2754	3747	124	2.2	7.3	1400	974	579
Type of Territory By Percentages																												
Urban		40	40	50	35		100									23.2	100				100			36			95	0
Suburban		30	30	40	35	100		21			100		100		100	0			100	100		100	100	0	100	100	5	40
Rural		30	30	50	30			79		100						76.8		100						64			0	60
Voltage of System - KV		2.4	6.6	23.6	23.6		4	6.6	4	11.95	4.85	4	13.2	4.04 13.2		23-13	2.3-13		23-13		2.4	4		13			2.4	6.9
Phase Connection		ΔY	Δ	Δ	ΔY		Y	Y	Y	Y	Y	Y	Y	Y		Δ	Δ		Δ		ΔY			Δ			Δ	Δ
Fusing Schedule - %				300				200	200															1340			240	240
Position L.A. With Respect To Fuse	All on Line			Side		Line	Both	Both	Both	Both	Line	Line	Line		Line	Line	Line		Line		Line			Line			Both	Both
Average Ground Resistance - Ohms	25	20	20		20-25	13.43	13	15	22	23	17	3	3	3	30		25	To 300	35			12.2				10	20	15
Failures Per 100 Installations																												
Primary Fuses Blown					3.42	0.92	8.26	0.72	4.85	2.53	0.83	46.1	1.15	8.80	5.48	2.35	10.75	6.70	2.75	1.54	2.30	4.03	4.54	4.10				
Transformer Winding	1.10	0.78	1.35	1.00	1.00	0.12		1.68	0.27	0.21	0.61	15.4	0.71	1.05	0.33	0.10	0.70	0.45	0.13	0.25	0.17	0	4.54	0.68	0.71	0.41	0.52	
Primary Only								0.48	0		0.05	15.4	0.16									0	0	0				
Secondary Only								0.24	0		0.05	0	0.05									0	0	0				
Primary & Secondary								0.96	0.27		0.30	0	0.43									0	4.54	0.68				
Lightning Arrester					0.34	0.17	2.95	0	1.89	0.39				0.88	0.08	0	0.40	0.36	0		0	4.09	0	3.43				
Customers' Meters Burned Out	0			0	0	0.08		0.48	0	0.04				0	0	2.45	1.33	1.45	0		0	0	0	0				
Customers' Wiring, Etc. Damaged				0		0.47				0.47				0.70	0	0	0	0.11	0		0	0	0	0	1.85			
Grounded Tanks			Yes	Yes				Some	Some		Some	Some	Some			No	No											

Company	31			33			34			35	36			37			39			39	40
Year	1934	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1935	1936	Avg.	1934	1935	1936	Avg.	1935	1936	Avg.	1935	1933
No. of Installations Reported On	3380	551	3946	4939	4366	476	1143	1983	3362	3343	3272	3325	51	4033	3314	2394	3520	3601	1886	2725	473[a]	1688	1635	1296	2351	1258	2290	2109
Type of Territory By Percentages																												
Urban	100	90		100	90	75.8		100	100	100	100		100	60	75		100	100	100		30	30	100	60	80	80	80	66
Suburban					0	0								20	15						30	50		10	10	10	10	0
Rural		95			10	24.5								20	10						0	0		10	10	10	10	34
Voltage of System - KV	4	11			24-66	23-66		2.3	2.3	2.3	2.3		4	4	4	4		4		2.3-11	2.3-11	2.3-11	2.3-11	2.3-11	4		
Phase Connection	Y	Y			Δ	ΔY		Δ	Δ	Δ	Δ		Y	Y	Y	Y		Y		ΔY	ΔY	ΔY	ΔY	ΔY	Y		
Fusing Schedule - %								240	240	240	240		240	240	240	240		230*									
Position L.A. With Respect To Fuse	Line	Line			Both	Both		All on Line			Side		All on Line			Side		Line		Line	Line	Line	Line	Line	Line	Line	Line
Average Ground Resistance - Ohms	30				30	30								50	30-288	30-288	10	5	5-10	15-100	100	15-100	15-100	10	10	10	2	
Failures Per 100 Installations																												
Primary Fuses Blown	2.23	0	5.30	3.41	13.52	6.10	6.55	11.61	3.90	0.39	7.40	3.86	5.60	6.99	1.96	5.47	4.40	1.90	1.29	1.68	5.07	3.21	3.71	3.49				2.37
Transformer Winding	0.08	0.36	0.76	0.36	0.80	0.84	0.53	0.73	0.64	0.24	0.62	0.46			0.34	0.79	0.48	0.51	0.38	0.46	1.06	0.30	0.47	0.40		0.52	0.52	0.57
Primary Only									0.12	0.09	0.11																	
Secondary Only									0	0.03	0.15																	
Primary & Secondary									0.12	0.40	0.26																	
Lightning Arrester								0	0.03		0.02				0.04	0.21	0.09		1.78	1.78		0.16	0.26	0.21				0.33
Customers' Meters Burned Out															0.04	0.13	0.07									0	0	0.05
Customers' Wiring, Etc. Damaged															0.04	0	0.03									0	0	0.05
Grounded Tanks			No				Yes			No						No							No			No	

Table I (Continued). Summary of Operating Data by Company and by Year

Standard Connection—Figure 1

	7								8	9				10[c]					13					14				15				
	1935			1936				Avg.	1934	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936		Avg.	1934	1935	1936	Avg.	1934	1935		1936		Avg.
	13810	7404	7336	7113	14-636	3723	130	6634	4000	3515	7405	1125	811	872	4336	13000	6500	3300	7600	1932	5300	1965	1913	1932	4107	97	100	100	99	3287	518	403	545	500	400	550[d]	4071
																					37	100								74	0	0				
	37.5		100	100				100	100	100	100	100				100	100	100	100	100	27		100	100	100				100	26	100	0	100	0	100	100
																					36									0					
100	32.5	100			100	100	100																	100		100	100	100	100						
	2.34																																		
	6.4	4	4	4	4	4	4			4	23%	4	4	2.3		4	4	4	4	4	4	4	4	4	4	4.8	4.8	4.8	4.8		2.3	2.3	4.0	2.3	2.3	4.0	
	Δ	Y	Y	Y	Y	Y	Y			Y	13.8	Y	Y	Δ		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Δ	Δ	Δ	Δ		29.3W	Δ	Y	29.3W	Δ	Y	
										240	Δ	240	240	240	240											300	300	300	300							
	ALL	ON	LINE		SIDE					ALL	ON	LINE		SIDE			LINE		SIDE		ALL	ON	LINE		SIDE		LINE		SIDE		ALL	ON	LINE		SIDE	
46	200	200	200				<30		70	50	60	50	17.5	200		14	14	14	14	30	25	25	25	25		93.5	68	68	48.75 33.3							
27.7	13.3	11.3	2.33	3.89	15.3	18.98	26.9	9.74	2.73	27.4	50.3			42.7	1.11	1.07	2.82	1.35	0.35	1.60	0.58	0.68	3.95	1.53	13.6	14.0	32.0	21.9	7.80	2.90	6.60	2.73	3.60	9.25	7.27	7.09
4.77	0.52	0.43	0.13	0.27	0.69	0.89	0	0.46	0.88	2.91	2.71	1.69	6.17	4.47	3.01	0.14	0.16	0.23	0.16	0.10	0.25	0.06	0.18	0.36	0.21	1.09	0	0	0.34	3.46[e]			0			
	0.10	0.09	0.07				0											0.03			0.11	0.06	0	0.15	0.10		0	0					0			
	0.26	0.12	0.04				0											0.03			0.02	0	0	0.05	0.02		0	0					0			
	0.16	0.22	0.07				0											0.18			0.13	0	0.13	0.15	0.10		0	0					0			
	4.10	4.10	0.82	0.91	4.42	3.74	6.92	2.89	0.38			3.82	3.82	6.30	4.60	0.09	0.13	0.20	0.11	0.15	0.15	0.26	0.19	0.91	0.20	0	7.0	0	2.96	0.33	0	0	0	0	0.50	0	0.28
									2.50									0.035	0.089	0.05	0															
	0.26	0.14	0.03	0	0.58	0	0	0.13										0.004	0.002	0.003	0					0	1.0	0	0.34		0	0	0			
																										0	0	0			0	0	0			
				No	No	No	No					No	No					No				No	No	No				No						No	No	No	

	22[a]								23					24				25	26				27	28			29				30			
	1936							Avg.	1934	1935	1936		Avg.	1936			Avg.	1934	1934	1935	1936	Avg.	1934	1935	Avg.	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.
	165	25	210	65	248	13	75	1816	3481	1623	260	256	71	1897	2513	2780	350	5645	1500	4500	2050	2050	180	4390	4500	8010	11255	8	19[e]	14	5200	3300	8277	5532	16172	13850	7830	12624
	100			100		100		100	100	33.0	50	0	0	100	100		100		100		100		100		100			100	80	100			75			100	100	100	100
			100		100		100			14.4	2.0	10	0			100													20		100	15	100					
		100								30.6	30	90	100																0			10						
	2.3	2.3	6.3	6.9	6.9	12	24-12		2.34	4	2.3	13.8		2.3	4	6.3	2.3-13		4	4	4	4		2.4		4	4	4		416.6	446.9	446.9	4.8	4.8	4.8	4.8
	Δ	Δ	Δ	Δ	Δ	Y	Δ4Y		Δ4Y	Y	Δ	Δ		Y	Y	Δ	Δ4Y		Y	Y	Y	Y		Δ		Y	Y	Y		Y4Δ	Y4Δ	Y4Δ	Δ	Δ	Δ	Δ
	240	240	240	240	240	240	240		200	200	200	200		200	200	200	200													200	250	250		300	250	250
	LINE	LINE	LINE	LINE	LINE			BOTH	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE		LINE	LINE	LINE	LINE	LINE	TEAMS		LINE	SIDE		LINE	LINE	LINE	LINE	LINE	LINE	LINE
	10	10	7	7	7	7	7		38	38				40	40	40	40	12	80	75	75	75	75			73	70	70-73	30	20	20	20-30	15	10	0+	10
																																	15			
	0.75		2	0.65		23.05	26.65	16.68	1.15	3.21	1.54	0	0.39	8.43	1.81	1.87	0.90	18.0	1.45			1.90	5.76	7.23	3.97					0	0	0	5.76	7.15	5.15	5.74	2.72	1.01		1.93
	0.10	4.00	0.48	0	0.40	0	0	0.46	0	0.25	0	0	0	1.41	0.11	1.07	0.65	2.86	0.98		2.44	0.83	3.66	4.44	2.39	0.25	0.19	0.23	0	0	0	0.39	0.64	2.46	1.46	0.16	0.12	0.36	0.19
	0	0	0	0	0.40	0	0		0		0	0				0.80	0.54	2.00	0.75			0.05	0.28	0.36	0.14				0	0	0		0.39			0.05	0.04	0.01
	0	0	0	0	0	0	0		0		0	0				0.08	0.07	0.28	0.09			0	0.20	0.56	0.12				0	0	0		0.12	0.28		0	0	0
	0.10	4.00	0.48	0	0	0	0		0		0	0				0.20	0.04	0.37	0.14			0.78	3.26	3.39	2.08				0	0	0		0.12			0.09	0.32	0.17
									0.03	0.12			0.06	0.68	0.29	3.43	1.36					0.15	0.34	0	0.23				0	0	0			0.02	0.02	2.17	0.35		1.61
									0	0.06	1.15		0.07									0.05	0.58	2.78	0.42								0.25		0.25			
									0	0			0																				0.29	0	0.18			
	No	No	No	No	No	No	No	No			No	No	No		No	No	No	No				No	No	No					Some	Yes			No			Some	

	42	43	44			45	47	50			55	67			68	69			70			
	1935	1935	1935	1936	Avg.	1936	1935	1935	1936	Avg.	1936	1935	1936	Avg.	1935	1935	1936	Avg.	1936			Avg.
	13638	6000	1027	738	4071	689	1651	1318	1542	1220	2966	315	363	1284	985	172	1404	1000	15	12	14	84	10	45	94	98	331
		67	0											100								100					
		0	0					100	53.5														100				
		0	100		100	80	5	0	0						100		100		100	100	100			100			100
		.33				20	35	0	44.5			100													100	100	100	
	24-12	24-66	11.5	4	14-115	23-69	24-11	2.4	6.6	4	12	24-12	23-63	2.4	2.3	2.3	2.3	2.3		4.8	4.8	4.8	2.3	2.3	2.3	6.9	6.9	23.0	23.0	
	Δ4Y	Δ4Y	Y	Y	Y	Δ4Y	Δ4Y	Y	Y	Y	Y	Δ4Y	Δ4Y	Δ	Δ	Δ	Δ	Δ		24W	24W	24W	Δ	Δ	Δ	Δ	Δ	Δ	Δ	
		200	4.50	4.50						250	250	250		400				250								230				
	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	LINE	TEAMS	TEAMS	TEAMS	TEAMS				LINE				
		13	20-25					17	17	16.3	16.5	17	28		668	668	668	668	25.50											
	4.01	3.55	10.70	2.22	3.89	8.85	15.1	3.51	21.7	3.05		8.65	14.29	4.68	0	8.19	18.02	4.60		0	8.33	3.70	1549	10.00	6.67	21.3	6.13	13.0		
	0.24	0.62	0.67	0.16	0.26	0.81	0.58	1.57	0.46	1.36	0.41	1.01	1.27	1.10	0.08	0.51	0.58	0.39	0.59	0	0	0								
		0.05					0.38	1.09	0.39	0.71	0.16	0.63		0.59	0.08	0	0.58	0.14	0.07	0	0	0								
		0.02					0	0.12	0	0.13	0	0.01		0	0	0.20	0	0.07	0.03	0	0	0								
		0.55					0	0.36	0.08	0.52	0.25	0.31		0.55	0	0.30	0	0.18	0.49	0	0	0								
		0.44				0.20								0.28	0	0	0.58	0.07		0	0	0			2.22					
			0			3.64	0	0	0	0	0	0	1.90	0	0	0.10	0	0.04		0		0	2.38			1.06		1.65		
			0				0	0	0					0						0		0								
				No		No				No	No				No	No	No				No		No	No	No	No	No	No		

a. Covers 45% of Installations.
b. 34 Transformers.
c. Failures per 100 Installations taken from Company rates
d. 550 34 Transformers.
e. Includes both bushing and winding.
f. Installation total includes a few interconnected transformers however, all failures were on Standard Connection
g. No Spark gap used.
h. 3 Years

Table II. Summary of Operating Data by Company and by Year

Solid Interconnection—Figure 2

Company / Year	2 1934	2 1935	2 1936	2 Ave.	4 1934	4 1935	4 1936	4 Ave.	6 1934	6 1935	6 1936	6 Ave.	7 1934	7 1935	7 1936	7 Ave.	8 1934	9 1934	9 1935	9 1936	9 Ave.
No. of Installations Reported On	3708	3051	3577	3577	302	30	546	25	25	603	253	215	783	4652	5031	1154	3404	6.12	4951	28	833	1521	801	154	3336	9251
Type of Territory by Percentages																										
Urban	100	80	73	100	100	70		0	0	100			100	218	100											60
Suburban		20	17			0		50	50		100			62.7		100		100	100					100		40
Rural		0	10			30		50	50			100		19.5			160			100	100	100	100			0
Voltage of System - KV	2.4	2.4	2.4	2.4	2.3	2.3	2.3	11	13	2.3-4	2.3-4	2.3-4	23-13	4	4	4	4	4	4	4	4	4	4	4		2.4
Phase Connection	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	ΔorY	ΔorY	ΔorY	ΔorY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Δ	Δ
Fusing Schedule - %	200	200	200	200						230	230	230	230													
Position L.A. With Respect To Fuse	Trans	Trans	Trans	Trans		Trans	Bush	Line	Line	80%	Trans	All	Bush	Trans	Trans	Trans	Trans	Trans	Trans	Line	Line	Line	Line			
Average Ground Resistance Ohms	3				25	29.7	4.5	15	15	4	6	6		5	6.7	6.7	6.7	6.7	6	8.7	2.5	2		70	120	20
Failure Data Per 100 Installations																										
Primary Fuses Blown	0.94	1.67	2.68	2.13	13.5	1.11	4.58	0	0	3.03	10.65	4.19	7.70	1.38	0.86	0.26	1.97	2.48	1.52	0	3.64	5.85	4.50		53.3	
Ratio Change over Std. Connection %	100.0	44.9	48.9	65.3	21.3	2.27	9.37	0	0	85.6	216.3	19.5	64.0	81.5	61	50.1	70.3	45.6	56.4	0	32.2	29.5	46.2		64.2	
Transformer Winding	0.14	0.34	0.36	0.32	0.40	0	0.18	0	0	0.29	0.40	0	0.29	0.16	0.22	0.35	0.18	0	0.19	0	0.47	0.86	0.71		1.79	0.66
Ratio Change over Std. Connection %	69.9	30.0		68.0	43.5	0	2.89	0	0	33.8	42.1	0	19.1	80.5	122	∞	17.6	+	73.0	0	109	112	57.7		63.9	15.2
Primary Only						0	0.18	0	0	0.29	0	0	0.16		0	0.09	0.09	0	0.09	0	0.12					
Ratio Change over Std. Connection %						0	5.40	0	0	85.3	0	0	22.5		+	∞	∞	+	∞		13.3					
Secondary Only						0	0	0	0	0	0	0	0		0.04	0	0.03	0	0.03	0	0.18					
Ratio Change over Std. Connection %						0	0	0	0	0	0	0	0		∞	+	3.94	+	12.5		10.0					
Primary & Secondary						0	0	0	0	0.40	0	0.08			0.18	0.26	0.05	0	0.14	0	0.29					
Ratio Change over Std. Connection %						0	0	0	0	83.3	0	8.33			100	∞	23.1	+	80.4		10.4					
Lightning Arrester	0	0.33	0.04	0.20	0	0	1.46	0		0.28	1.19	3.72	0.90		0.38	0.17	0.21	0.40	0.29	3.87	0.94	0.86	0.92			
Ratio Change over Std. Connection %	0	43.8	13.3	13.5	0	0	18.25	+		104.0	380.5	1352	110.0		∞	∞	∞	∞	∞	102.1	23.9	20.7	31.8			
Customers' Meters Burned Out	0.32	0.59		0.30	0.40	0	0	0		0.49	0	0.47	0.26			1.38	2.46	0.65	2.01							
Ratio Change over Std. Connection %	83.7	83.9		36.1	36.3	0	0	+		36.0	0	4.06	11.10			30.6	32.6	24.1	13.6							
Customers' Wiring, Etc. Damaged	0				0.40	0	0	0		1.01	0	0	0.39		0.68	3.29	0.33	0.16	0.83		0.23	0.66	0.31			
Ratio Change over Std. Connection %	+				444	0	0	+		213	0	0	0.95		∞		13.5		63.0		16.4	21.2	38.1			

Company / Year	20 1934	21 1934	21 1936	21 Ave.	23 1934	23 1935	23 1936	23 Ave.	24 1936	28 1935	28 1936	28 Ave.	29 1934	29 1935	29 Ave.	30 1934	30 1935	30 1936	30 Ave.	31 1934	32 1934	33 1934	33 1935	33 1936	33 Ave.
No. of Installations Reported On	1300	4982	134	18	2967	819	2175	2137	2296	10	58	33	36	20	20	20	23980	30360	30480	33330	50	6851	966	815	411	637
Type of Territory by Percentages																										
Urban	100	100			100	100	98	100	100	100	80	100	100	33	100	100	TT	0	100	100	100	100	100	589	38.8
Suburban			100				2				20			48										0	0
Rural				100			0							0			52.3	100						6.1	1.2
Voltages of System - KV			13	13		4	4	4	2.3-4	4	4	4	4	4-6.6	4-6.6	4-6.6	4.8	4.8	4.8	4.8				24-66	24-66
Phase Connection			Y	Y		Y	Y	Y	ΔorY	Y	Y	Y		Y-Δ	Y-Δ	Y-Δ	Δ	Δ	Δ	Δ				Δ	ΔorY
Fusing Schedule - %			280	280		200	200	200	280					280	280	280	300	300	280	300						
Position L.A. With Respect To Fuse			Line	Line		Trans	Trans	Trans	Trans	Line	Line	Line		Line	Line	Line	Line	Line	Line	Line				Bush	Bush	Bush
Average Ground Resistance - Ohms	0.25	5.8			1	1	2	1-2		10	10	10	19	2	2	10	10	12	10-12		1	30		80	30
Failure Data Per 100 Installations																									
Primary Fuses Blown	1.46	0.85	1.49	0	0.81	0.80	1.20	0.22	0.50		0	0	0	0	0	0	2.19	1.89	2.02		0.31	1.50	4.68	2.52	3.01
Ratio Change over Std. Connection %	53.1	3.72	7	7	4.63	3.04	37.4	14.3	27.6		+	+	+	0	0	0	102.5	138	105		7	11.1	76.8	44.5	23.3
Transformer Winding	0.08	0	0	0	0	0.05	0.05	0.06	0.04		0	0	0	0	0	0	0.49	0.15	0.46	0.35		0.89	0.12	0.12	0.34	0.148
Ratio Change over Std. Connection %	62.5	+	7	7	0	∞	20.0	∞	40.0		+	+	+	0	0	0	309	125	128	169		7	14.5	14.9	45.9	19.1
Primary Only			0	0	0						0	0	0	0	0	0		0.06	0.13	0.10					
Ratio Change over Std. Connection %			4	7	7						+	+	+	0	0	0		200	338	239					
Secondary Only			0	0	0						0	0	0	0	0	0		0.08	0.05	0.06					
Ratio Change over Std. Connection %			+	7	+						+	+	+	0	0	0		∞	∞	∞					
Primary & Secondary			0	0	0						0	0	0	0	0	0		0.61	0.39	0.482					
Ratio Change over Std. Connection %			+	7	7						+	+	+	0	0	0		178	382	207					
Lightning Arrester	0	0.07	0	0	0.06	0	0.14	0.07	0.07		0	0	0	0	0	0	2.39	1.38	1.93	8.61					
Ratio Change over Std. Connection %	+	1.64	7	7		0	117		122		+	+	+	0	0	0	110	145	114	7					
Customers' Meters Burned Out	0	0	0	0	0	0	0.09	0.11	0.07					0	0	0		0	0	0	0	0.15			
Ratio Change over Std. Connection %	+	+	7	7	+	+	150	9.55	98.7					0	0	0				7					
Customers' Wiring, Etc. Damaged	0	0	0	0	0	0								0	0	0		0	0	0	0	0			
Ratio Change over Std. Connection %	+	+	7	7	+	+								0	+	0				7					

4. *Type CSP transformer* (figure 9) which is similar to the type *SP* transformer except a secondary breaker is used and a high-rating fuse link is installed in the transformer. The intention is that no primary fuse be used.

In each of the protection schemes described, except the type *SP* and *CSP* transformers, the primary fuse or fuses may be installed on either the line or transformer side of the lightning arresters. On three-phase four-wire systems except for type *SP* and *CSP* transformers the lightning arrester ground is interconnected with the primary neutral usually through a gap whereas on three-wire systems two arresters and primary fuses are used. These alternatives are indicated on figures 1 to 5 and 8.

Operating Results 1934–1935–1936

Detail Data by Companies

While the data collected have been summarized to draw various comparisons in the tables of this paper it is believed the principal value of a paper of this type is to include the detail data submitted by each operating company so that the information can be set up to draw

Table II (Continued). Summary of Operating Data by Company and by Year

Solid Interconnection—Figure 2

9	10					12	13					14					15					16					17					18	19			
1936				Avg.	1934	1935	1934	1935	1936		Avg.	1934	1935	1936	Avg.		1934	1935	1936	Avg.		1934	1935	1936	Avg.		1934	1936	Ave.		1934	1934	1935	1936	Ave.
7618	539	2344	857	12082	2000	2167	3604	2817	2841	1934	4301	858	2846	309	3426		37	100	99	99		4443	2165	2187	2819		900	2341	3668	2301		9	79	2	4.5	4.27	144	235	300	893	244
85	0	10	10																									60	30									
15	20	20	20	100	100	100	100	100	100	100	100																	20	40	100	100		100					
0	60	70	70																									20	30					0	0	100		100
																																		81.2	100		
																																		18.8			
A	4898	6.9	1540	24-138	4	4	4	4	4	4	4	4	4	4	4		4.8	4.8	4.8	4.8		2.4	2.4	2.4	2.4			2444	2.4 & 4	24-46			4	12		44.82		2.4	23-138	23-138	
Y	Δ4Y	Y	Δ4Y	Δ4Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Δ	Δ	Δ	Δ		2438	2438	2438	2438			Δ4Y	Δ6Y	Δ6Y			Y	Y		Y		Δ	Δ4Y	Δ6Y	
												300	300	300	300														300				200	200						
					Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line		Line	Line	Line	Line		Line	Line	Line	Line			Line	Line			Tower	Tower		Line		Line	Line	Line	
20	50	30	50		0.5	0.5	0.2	<0.5		2	3	2	2	2	2		22.8	17	17	17.23							25	20			10.5	1-5	1-5		3	30				
					0.39	0.39	0.76	0.51	0.43	0.13	0.41	0.22	0.35	0.13	0.36		10.01	10.00	18.20	12.82		0.54	0.60	0.56	0.76							1.27		1.27	0.47	5.6	2.55	1.67	18.83	3.83
					26.5	36.4	26.9	37.3	†	1	44.1	25.6	37.9	51.5	3.19		23.5	52.3	71.4	56.9		39.5	12.0	20.7	15.6	10.7						176		30.1	40.3	63.6	46.5	71.0	175	37.1
0.31	1.43	2.51	7.47	1.34	0.07	0.09	0.13	0.10	0.11	0.103	0.11	0	0	0	0.07		1.03	0	0	0.34		0.60	0.42	0.05	0.41		0.21	1.03	0.73			1.27	0	0.12	0.7	2.78	0	0	0	0.55
14.8				44.5	47.3	38.1	36.1	63.5	†	103	44	0	0	0	32.9		100	*	*	101		17.3					26.9	109	73			73.6	0	57.0	38.5	26.4	0	0	0	81.8
						0.02	0.02	0.07			0.02	0	0	0	0.01			0	0	0											1.27	0	0.12			0	0	0	0
						80.0	80.0	†			1.82	0	*	0	10.3			*	*	*											26.5	*				0			
						0.02	0.02	0.04			0.03	0	0	0	0.02			0	0	0											0	0	0			0	0	0	0
						96.4	96.4	†			2.50	*	*	0	1.05			*	*	*											0	*				0			
						0.08	0.08	0			0.03	0	0	0	0.02			0	0	0											0	0	0			0	0	0	0
						46.3	46.5	†			38.4	*	0	0	20.6			*	*	*											0	0				0			
	0				0.141	0.13	0.25	0.18	0.17	0.15	0.16	0.11	0.14	0	0.14		1.03	6.00	0	2.36		0.05	0.63	0.05	0.20							3.8	0	0.37	0	1.39	0.83	0	1.89	0.83
	0				164.1	101.0	124	159	†	1	102	107	55.0	73.7	0		71.7	∞	85.7	*		100	14.5	∞	∞	36.5							∞	0	94.9		158	698	*	472	198
7.34						0.05	0.09	0.08	0.36	0		0	0	0	0		0	0	0	0		0.87				0.87		0		0	0	0	0	0	0				0
						17.15	94.9	151.0	†	*							*	0	*	0							*		+	0	0	+	0			0	0			0
						0.003	0.003	0.001	0	0		0	0	0	0		0	0	0	0							0		0	0	0			0	0	0	0	0	0
						62.5	50.0	44.7	†	*							*	*	*	*							*		*	0	*			*	0	*	*	0

24	26				27			40	42	45	50				21			25	60		
1934	1935	1936	Avg.	1934	1935	1936	Ave.	1935	1935	1936	1934	1935	Ave.		1936	Ave.		1936	1934	1935	1936	Avg.
41	40	38	40	1152	1448	1521	1374	2049	2772	3418	1900	1885	1278	340	3	497	335	703	2.179	2237	4216	39	392	403	308
100	100	100	100		40	40					100		100	100	100										
				100	60	60	100	100	100	100		100							100						
					0	0														100	100	100	100	100	100
2.3	2.3	2.3	2.3	4	4	4	4	4	4	4	4	24-42	2.3	6.6	2.4	12	12		4	12		2.346	4.8	4.8	4.8
Δ	Δ	Δ	Δ	Y	Y	Y	Y	Y	Y	Y	Y	Δ6Y	Δ	Y	Y	Y	Y		Y	Y		Δ6Y	2468	2468	2468
230	230	230	230	230	230	230	230	250	250	250									240	244	240				
Tower	Tower	Tower	Tower	Line	Line	Line	Line	Line	Line	Line	Tower	Line	Line	Line	Tower	Line			Tower	Tower	Tower	Line	Tower	Tower	Tower
0	0	0	0		0.5	0.2		10.0	5.0	8-10	1.0			17	19				4	10		2.8	14.1	14.1	14.1
4.88	5.00	7.30	5.88	2.37	0.56	1.11	1.32	1.02	0.35	0.58	1.40	4.30	1.88		0		0		1.14	5.30	5.62	1.70	18.6	5.22	8.30
12.5	1290	107	152	339	28.6	20.3	30.0	68.7	18.4	34.5	42.1	107	21.2		0				†	†	†	11.9	∞	38.6	2.24
0	0	0	0		0.11	0.13	0.12	0.30	0.16	0.21	0.26	0.27	0.16	0.88	0		1.01	0.18	0.64	0.89	0	0.28	0.14	0	0.31	0.25	0.38
0	0	0	0		32.4	16.4	25.0	57.7	16.8	45.0	28.1	112	18.7	180	0		246	44.0	62.3	†	†	†	0	∞	∞	∞
0	0	0	0								0.11			0.38	0		0.40	0	0.21	0	0.10	0.05	0	0	0	0
	0	0	0											13.8	0		2.50	0	88.7	†	†	†		4	4	4
0	0	0	0								0			0.67	0		0.60	0	0.833	0	0	0	0	0.25	0.25	0.25
	*	0	0								0			∞	0		∞	*	504	†	†	†		∞	∞	∞
0	0	0	0								0.05			0	0	0	0	0.18	0.07	0.09	0.10	0.18	0	0.23	0	0.13
	0	0	0											0	0	0	0	72.0	32.6	†	†	†		∞	4	∞
0	0		0		0.10	0.12	0.11		0.50	0.30	0.16		0.31		0					0.64	1.08	0.85		1.79	0.80	1.19
*	0		0		230	57.1	121		28.1	28.1	48.5		14.8		0					†	†	†		∞	∞	∞
					0.01	0.03	0.02				0		5.87	0	0	0		0		0.05	0.05	0.05	0	1.28		1.28
					23.0	23.1	23.0				0		16.1	*	*	*		4		†	†	†	0	∞		∞
					0	0	0				0			0	0					0	0	0	0	0.51		0.89
					0	*	0				0			*	*					†	†	†		∞		∞

* No failures either connection.
† Standard Connection not used.
○ Not directly comparable with Fig. 1.
a. Lightning arrester used on each wire.
c. Includes some Capped Interconnection.
d. Includes some Capped Interconnection.
e. Spill gap used instead of lightning arr.

any comparison desired. The data submitted by each company for the three-year period have been included in tables I to IX. Each table covers a type of protection. All failures and primary fuses blown are those attributed to lightning. All rates of trouble are the number per 100 transformer installations. Primary fuses blown are exclusive of those blown by arrester or transformer failures.

Comparison of Various Schemes of Protection

In tables X, XI, and XII the data have been summarized for the three years. Since in 1935 and 1936 the data was obtained in more detail, tables XIII, XIV and XV have been prepared covering average data for these two years. Since the reports for many companies did not segregate operating data by types of territory tables X and XIII represent a greater number of installations than the sum of those represented in the component tables covering rural and more thickly populated territories. In the summary tables, i.e., X to XXIV, the average number of transformer installations in each case is the average of the total installations for the years covered in each table. However, the trouble rate for

Table III. Summary of Operating Data by Company and by Year

Solid Interconnection With Tie to Case—Figure 3

Company	2	4					11			13	16			18	33		
Year	1935	1934	1935		1936	Avg.	1933	1936	Avg.	1936	1935	1936	Avg.	1936	1935	1936	Avg.
No. of Installations Reported On	103	35	7	514	31	58	2.15	1477	1500	1489	103	570	916	743	28	45	79	62
Type of Territory By Percentages																		
Urban	100			48	0			100	100	100		30	20			100	82.3	88.7
Suburban				17	39							50	30				0	0
Rural		100	100	35	61	100	100				100	20	50	100	100		17.7	11.3
Voltage of System - kv	4	11-13.2	2.4	2.4	11	23-11.2		2.4	2.4	2.4	4	6.9	6.9	6.9	13.2	24-6.6	24-12	
Phase Connection	Y	Δ	Δ	Δ	Y	Δ Y		2-Ph W	2-Ph W	2-Ph W	Y	Δ	Δ	Δ	Y	Δ Y	Δ Y	
Fusing Schedule - %						300							300					
Position L.A. With Respect To Fuse	Line		Trans	Line	Trans	Both		Line	Line	Line	Line	Line	Line	Line	Line		Both	
Average Ground Resistance - Ohms		20	36		133	10		0.10	0+	0+	2	20			0.5		30	
Failure Data Per 100 Installations																		
Primary Fuses Blown	4.85	22.8	0	6.03	0	24.15	8.22	0.07	0	0.03	0.37				30.0		5.06	5.06
Ratio - Change over Std. Connection - %	74.2		0	12.3	0	78.0	68.3	1	1	1	24.6				108		77.3	43.5
Transformer Winding	0.97	14.3	0	1.36	0	0	1.86	0	0	0	0	0.53	0.11	0.37	7.15	0	1.27	0.81
Ratio Change over Std. Connection - %	5.70		0	21.8	0	0	1.42	1	1	1	0	39.3	11.0	37.1	46.5	0	240	107
Primary Only			0	0.39	0	0	0.33	0	0	0	0					0		
Ratio Change over Std. Connection - %			0	11.7	0	0	46.2	1	1	1	0							
Secondary Only			0	0.39	0	0	0.33	0	0	0	0					0		
Ratio Change over Std. Connection - %			0	35.2	0	0	109.2	1	1	1	0							
Primary & Secondary			0	0.58	0	0	0.49	0	0	0	0					0		
Ratio Change over Std. Connection %			0	32.6	0	0	82.0	1	1	1	0							
Lightning Arrester		0	0	0.19	0	0	0.16	0	0	0	0							
Ratio Change over Std. Connection - %			0	2.44	+	0	18.9	1	1	1	0							
Customers' Meters Burned Out		0	0	0	0	0	0	0	0	0	0		0	0				
Ratio Change over Std. Connection - %			0	0	+	0	0	1	1	1			+	+				
Customers' Wiring, Etc. Damaged		5.72	0	0	0	0	0.31	0	0	0	0		0	0				
Ratio Change over Std. Connection - %			0	0	+	0	73.6	1	1	1			+					
Tie to Case - Solid(S) or Gapped(G)	S	S	S	G	G	Both	Both	S	S	S	S	S	Both	Both	S	G	G	G

\+ No failures either connection.
\+ Standard Connection not used.

a. Includes some Gapped Interconnection with Tie to Case.

Table IV. Summary of Operating Data by Company and by Year

Gapped Interconnection—Figure 4

Company	1	4					6a				7	13	14			19			
Year	1935	1935			1936	Avg.	1934	1935	1936	Avg.	1936	1936	1934	1935	1936	Avg.	1934	1935	1936	Avg.
No. of Installations Reported On	1000	373	23	89	191	130	690	858	646	707	174	638	691	260	98	101	101	100	72	998	50	1220	780	139
Type of Territory By Percentages																								
Urban	0	7		3	100					21.0	100										100		21.3	4.3
Suburban	30	5		10		100		100		30.2		100												6.0
Rural	88	88	100	87			100		100	41.6			100	100	100	100	100	100	100	100		100	78.7	85.7
Voltage of System - kv	4-13	2.4	7.6	13	23-13.2	23-13.2	23-13.2	23-13.2	4	4	4	4	4	4	4	4	4.6	4.8	4.8	4.8	24-13.2	24-18	24-13.8	24-13.8	4
Phase Connection	Y	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Y	Y	Y	Y	Y	Y	Y	Y	Δ	Δ	Δ	Δ	Δ Y	Δ Y	Δ Y	Δ Y	Y
Fusing Schedule - %					250	250	250										300	300	300	300					200
Position L.A. With Respect To Fuse	Line	Both	Both	Trans	Both	Both	Both	Both	Trans	Trans	Trans	Trans	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Trans
Average Ground Resistance - Ohms	15	30	60	20	25	50	50	58	8	250	250	250	250	174	2	25	101	75	75	83	30				10
Failure Data Per 100 Installations																									
Primary Fuses Blown	3.80	10.1	4.35	38.5	10.5	28.0	10.0	14.10	3.13	1.27	5.89	3.69	3.44	2.68	3.96	1.92	3.2	13.9	2.28	18.33	7.20	3.91	8.00	7.37	5.90	5.02
Ratio Change over Std. Connection - %	88.6	207	7.34	652	256	358	324	117	141	90.0	116	132	63.7	114	22.3	42.5	47.8	192	72.2	710	61.0	71.4	340	62.5	88.1	106
Transformer Winding	0.70	0.35	4.35	0	0.52	1.33	1.01	0.76	0.15	0.14	0	0.52	0	0.23	0.45	0	0	1.58	1.98	1.33	0	0.10	0	0.74	0.43	0
Ratio Change over Std. Connection - %	66.6	5.62	28.2	0	97.0	140	387	580	18.0	77.8	+	90.1	+	110	58.5	0	0	∞	∞	396	0	50.3	0	106	93.2	+
Primary Only	0.60	0.35	4.35	0	0	0.67	0.38	0.47		0	0	0.46	0	0.14			0	0	0.99	0.39	0.66	0				0
Ratio Change over Std. Connection - %	68.2	10.5	113	0	0	186	60.5	146.2		+	+	∞	+	∞			0		∞	∞						+
Secondary Only	0.10	0	0	0	0	0	0.45	0.06		0.14	0	0	0	0.07			0	0	0	0	0	0				0
Ratio Change over Std. Connection - %	62.5	0	+	0	0	0	21.0	20.0		∞	+	0	+	26.6			0		+	+						+
Primary & Secondary	0	0	0	0	0.52	0.67	0.29	0.23		0	0	0.46	0	0.14			0	0	0.99	0.99	0.66	0				0
Ratio Change over Std. Connection - %	+	0	0	0	388	438	30.2	38.4		0	+	177	+	78.3			0		∞	∞						+
Lightning Arrester	4.00	2.10	0	13.5	2.62	1.33	0.72	2.10		0.42	0	0.69	0.24	0.48	0.23	0.38	0	4.96	0	1.33	1.29	0.30	2.00	0.37	0.91	0
Ratio Change over Std. Connection - %	172	27.0	0	∞	97.0	198	36.2	256		∞	+	∞	∞	∞	7.80	12.5	+	86.6	+	36.3	136	57.5	∞	143	143	
Customers' Meters Burned Out	0.20	2.62	0	13.8	4.18	4.66	2.08	3.26									0	0	0	0	0	0				0
Ratio Change over Std. Connection - %	10.0	147	+	∞	346	140	17.2	27.6										4	0	+	0	+	+			0
Customers' Wiring, Etc. Damaged	0	0	0	0	0	0	0.13	0.06		0.28	0	0.46	0	0.28	0.11	0	0	0	0	0	0	0				
Ratio Change over Std. Connection - %	+	0	+	4	0	0	30.2	19.3		∞		177		276	85.5		+	4	+	+	0	+				

\+ No failures either connection.
\+ Standard Connection not used.

a. Not directly comparable with Fig. 1. b. Lightning Arrester used on neutral.

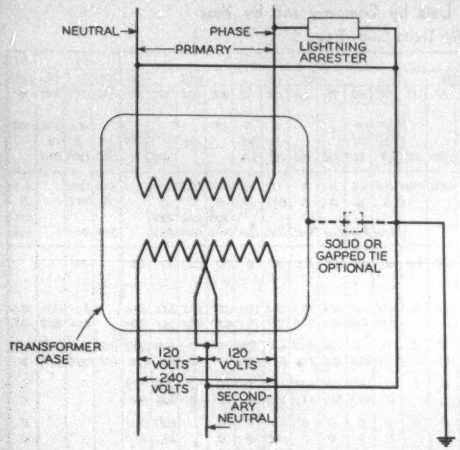


Figure 6 (left). Common primary and secondary neutral

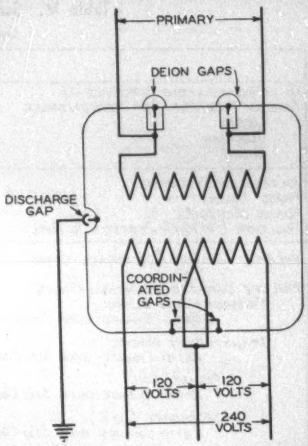


Figure 7 (right). Surge-proof transformer

each item of trouble is determined by taking the sum of troubles for each item for the period under consideration as a percentage of the sum of the installations on which data were reported for that item. Since very few companies failed to supply data for primary fuses blown, transformer winding failures, and lightning arrester failures, the trouble rate in each of these cases may be considered as based upon the average of the total number of installations shown in the tables. However in the case of the segregation of the location of transformer winding failures, a number of companies did not supply segregated data. Therefore, the sum of the segregated rates will not equal the total rates of transformer winding failures.

In comparing the relative *rates of primary fuses blown* using the various protective schemes, a study of tables X to XV shows that the schemes using solid interconnection show the lowest rate of primary fuses blown using any of the six bases of comparison. Where sufficient data is available to compare the conventional solid interconnection, the interconnection with tie to transformer tank; and the common primary and secondary neutral,

Table IV (Continued). Summary of Operating Data by Company and by Year

Gapped Interconnection—Figure 4

'33	'34	'35	'36	'37	'38	'39	'40	'41	'42	'43	'44	'45	'46	'47	'48	'49	'50
1936 Avg.	1936 Avg.	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	Avg.
76 9	209	660 350	1010	2543	2419	2481	57	58	53	56	193	4434	5083	4639	202	131	151	168	527	357	442	400	112	50	50	50	2380	447	122	136	123	153	10	8	12	121	26	20	350
0					18.3	8.9						0	0	0					75	80																			
53	100	100	100		0							10	10	10	100	100	100	100	15	10	100							100	100		100			100			100
47 100			100	100	81.7	91.1	100	100	100	100	100	90	90	90					10	10		100	100	100	100	100	100											
2.3 13.8			4 4	4	24-12	23-12	23-12	2.4	2.4	2.4	2.4	4	4	4	4	4	4	4	24-12	24-12	24-12	4	4	11.5	11.0	11.0	6.9	23-10	4.8	4.8	4.8	2.3	13	13.2	2.3	2.4	12	13.8
Δ Δ			Y Y	Y	Δ	ΔY	ΔY	Δ	Δ	Δ	Δ	Y	Y	Y	Y	Y	Y	Y	ΔY	ΔY	ΔY	Y	Y	Y	Y	Y	Y	ΔY	2Ø4W	2Ø4W	3Ø4W	Δ	Y	Δ	Δ	Δ	Δ	Δ
200 200								240	240	240	240	240	240	240					200	200	200			4.80	4.80	4.80						200	200	200	200			
Trans Trans			Line Line	Line	Both	Both	Both	Line	Line	Line	Line	Trans	Trans	Trans	Line	Line	Line	Line	Trans	Trans	Trans	Trans		Line	Line	Line	Line	Line	Trans	Trans	Trans	Line	Line	Line	Trans	Trans	Trans	
10 10		10	73 73	75		30		0				20	20	20	17 to 100	17% 100	17 to 100	15 to 100	10	10	10	2.5		13	20.5		28					15	15	15	6	5.5	6.5	
0 11.1	2.46	1.06	8.86	3.76	0.25	7.06	3.06	0	3.45	7.53	2.80	30.0	10.0	13.40	14.41	0.97	0.66	2.65	1.39				3.00	3.17	10.0	10.0	11.0	6.20	4.52	13.9	2.96	9.15	0.65			0	0	0	0.31
0 13.1	1.36	18.6	1.23	9.47	1.35	1.20	6.35	0	6.84	1.02	12.5	5.35	5.10	3.36	3.28	13.1	20.6	70.6	39.8				1.26	6.30	9.34	4.90	2.57	7.01	3.44	∞	35.3	2.20	4.20			0	0	0	2.40
0 0	0	1.06	8.00	3.46	0.04	0.41	0.22	0	0	0	0	0.63	0.36	0.81	0.33	0.66	0	0.40	0	0	0	0.30	0	0	0	0.43	0.22	0	0.79	0.39							
4 0	0	29.0	180.	14.5	4.50	77.3	29.6	0	0	0	0	185	12.2	16.8	31.1	22.0	0	99.0	0	0	0	87.7	0	0		53.1	17.3	4	∞	∞							
0 0	0	0	0	0				0	0	0	0						0		0	0	0		0	0	0			0	0.76	0.39							
4			0 0						0	0	0												0	0				4	∞	∞							
0 0	0	0.13	0	0.10				0	0	0	0						0		0	0	0		0	0	0			0	0	0							
4			7.5 0						*	0	0												0	0				4	*	4							
0 0	0	0.31	8.00	3.37				0	0	0	0						0		0	0	0		0	0	0			0	0	0							
4			21.9 2.40						0	0	0												0	0				4	*	4							
0 0	0	0.30	1.43	0.69				0				0.54	1.38	0.98		0.66	0.66	0.66	0	0	0	0.78		0	0	0	0.12		0.82	0	0.39				16.67	0	0	0	1.18
		88.2	∞					*				1330	6.57	1030		4.12	2.54	3.14				22.7		0	0		57.1		∞	4	∞				750	0			30.5
0 0	0	2.38[a]	13.4[a]	6.16[a]								0.03	0.26	0.13					0	0	0	0		0	0	0	7.16	0.22	0.82		0.82				8.33	3.31			
	0	3.93	4.82									30	200	223	39.0							0		0			196	11.6	∞		∞					139			
												0.08	0.14	0.11	2							0		0					4		*					8.27			
												22.5	∞	4.58								0		*														

a. Company estimate. d. As compared with surrounding area.

Table V. Summary of Operating Data by Company and by Year

Gapped Interconnection With Tie to Case—Figure 5

Company / Year	4														39			54
	1934				1935						1936		Avg.		1935	1936	Avg.	1936
No. of Installations Reported On	120	354	20	27	193	60	70	66	196	13	62	124	367	597	312	777	546	10[a]
Type of Territory by Percentages																		
Urban	48	90			6	0			2	0	100					4.6	3.30	100
Suburban	34	10			25	22			0	38		100	100			0	0	
Rural	41	0	100	100	69	78	100	100	98	62					100	95.4	96.7	
Voltage of System - KV	2.3	2.3	11-13.2	11-13.2	2.4	6.6	11	11	13	13	2.3-13.2	2.3-13.2	2.3-13.2		6.6	2.3-12		2.3
Phase Connection	Δ	Δ			Δ	Δ	Δ	Δ	ΔorY	Δ	-Δ	Δ	Δ		Δ	ΔorY		Δ
Fusing Schedule - %											250	250	280					230
Position L.A. With Respect To Fuse					Both	Trans	Line	Trans	Both	Line	Both	Both	Both		Both	Both		Line
Average Ground Resistance - Ohms	75	25	25	60	60	54	30	23	30	6	20	25	25	38		30		
Failure Data Per 100 Installations																		
Primary Fuses Blown	0.83	2.26	20	111	4.15	1.67	14.3	30.3	13.0	15.4	37.1	35.5	44.6	27.6		8.11	8.11	10.0
Ratio - Change over Std. Connection - %					8.50	2.30	15.9	33.6	83.5	17.2	105[1]	454	145	230		124	63.9	135
Transformer Winding	0.83	0	0	0	0	1.67	2.86	3.03	4.08	7.70	0	0	3.54	1.67	0.96	0.26	0.46	0
Ratio Change over Std Connection - %					0	10.8	16.6	17.6	23.7	44.7	0	0	135	128	114	49.0	61.3	0
Primary Only		0	0	0	0	1.67	2.86	1.52	3.57	0	0	0	2.45	1.29				0
Ratio Change over Std. Connection - %					0	43.3	82.9	44.0	103	0	0	0	256	182				0
Secondary Only		0	0	0	0	0	0	0	0.51	0	0	0	0.27	0.13				0
Ratio Change over Std. Connection - %					0	*	0	0	14.8	0	0	0	39.1	43.0				0
Primary & Secondary		0	0	0	0	0	0	1.52	0	7.70	0	0	0.82	0.32				0
Ratio Change over Std. Connection - %					0	0	0	14.8	0	74.6	0	0	85.5	53.7				0
Lightning Arrester	0		0		2.59	0	0	0	5.10	0	0	0	2.45	1.86				
Ratio Change over Std. Connection - %					33.3	0	*	*	∞	*	0	0	89.1	227				
Customers' Meters Burned Out	0	0	0	0	0	0	0	0	0	0	0	0	1.96	0.90				
Ratio Change over Std. Connection - %					0	*	*	*	*	*	0	0	11.5	12.8				
Customers' Wiring, Etc. Damaged	0	0	0	0	0	0			0	0	0	0	0	0				
Ratio Change over Std. Connection - %					0	*			*	*	0	0	0	0				
Tie to Case - Solid (S) or Gapped (G)	G	G	S	S	S	S	S	S	S	S	Both	Both	Both		G	S		G

* No Failures either connection.

a. Slight modification of Fig. 5.

Table VI. Summary of Operating Data by Company and by Year

Solid Interconnection Obtained by Common Primary and Secondary Neutral—Figure 6

Company / Year	1	3			4					9			11			12			13	
	1935	1935	1936	Avg.	1935	1936			Avg.	1934	1935	Avg.	1936	1935	Avg.	1934	1936	Avg.	1935	1936
No. of Installations Reported On	10	52	5300	2771	7	7	29	42	572	329	3373	6364	4970	4709	737	2733	3175	3430	2883	1050	301	1142
Type of Territory by Percentages																						
Urban			100			100	100			100	100	100	100	100	100	100	100	100	100	10	100	
Suburban								100	100											40		100
Rural	100	70-90			100															50		
Voltage of System - KV	2.4	13	44123		2.4	4	4, 11, and 13.2				4	4	4	4	4	4	4	4	4	4	4	4
Phase Connection		Y	Y				Y				Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fusing Schedule - %	240						230	230	250		240	240	240									
Position L.A. With Respect To Fuse	Line	Line	Trans		Trans	Trans	Trans	Trans	Trans	Trans		Both	Both	Line	Line	Line	Line	Line	Line	Line	Line	Line
Average Ground Resistance - Ohms	2				18	3	3	3	3	30	10	30	35	0.6	0+		1.0	0+	0-1		20-	20-
Failure Data Per 100 Installations																						
Primary Fuses Blown	0	7.69	2.95	2.99	0	0	0	11.9	8.32	8.53	6.10	0	2.20	0.06	1.32	0.26	0.12	0.40	0.38	0.76	1.33	1.05
Ratio - Change over Std Connection - %	0	44.4	46.0	34.9	0	0	0	152.0	28.9	76.9	22.2		5.15	†	†	†	†	†	†	47.5	22.9	15.4
Transformer Winding	0	0	0.58	0.56	0	0	0	0	1.57	1.37	0.78	0.13	0.40	0.04	0.40	0.09	0.22	0.36	0.28	0	0	0
Ratio Change over Std Connection - %	0	0	45.4	35.4	0	0	0	0	60.1	104	28.2	11.2	13.4	†	†	†	†	†	†	0	0	0
Primary Only	0	0			0	0	0	0	0.35	0.30				0.40			0.20			0	0	0
Ratio Change over Std Connection - %	0	0			0	0	0	0	36.5	42.2				†			†			0	0	*
Secondary Only	0	0			0	0	0	0	0.35	0.31				0						0	0	0
Ratio Change over Std. Connection - %	0	0			0	0	0	0	50.7	102				†						0	*	*
Primary & Secondary	0	0			0	0	0	0	0.87	0.76				0						0	0	0
Ratio Change over Std Connection - %	*	0			0	0	0	0	90.6	127				†						0	*	0
Lightning Arrester					0	0	0	0	0.87	0.76		0.49	0.49	0.02	0.59	0.09	0.22	0.24	0.23	0	0	0.09
Ratio Change over Std. Connection - %					0	0	0	0	31.6	92.9		12.8	10.7	†	†	†	†	†	†	0	0	47.4
Customers' Meters Burned Out	0				0	0	0	0	0.17	0.16				0.02	4.10	0.59	0.22	1.65	0.85			
Ratio Change over Std. Connection - %	0				0	0	0	0	1.44	6.49				†	†	†	†	†	†			
Customers' Wiring, Etc. Damaged	0				0	0	0	0	0	0				0	0	0	0	0.04	0.02			
Ratio Change over Std Connection - %	*				0	0	0	0	0	0				†	†	†	†	†	†			
Grounded Tanks	No	No	Yes		No	No	Yes	Yes	Yes			No			Some			Yes		No	No	No

* No failures either connection.
† Standard Connection not used.

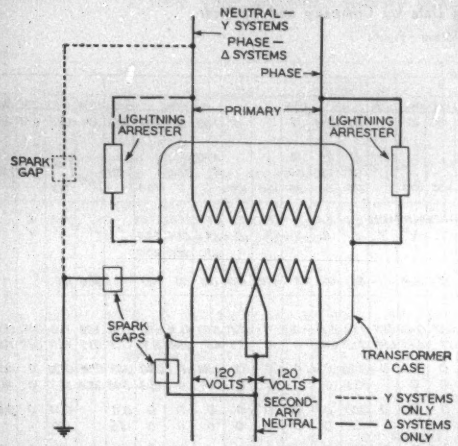


Figure 8 (left). Three-point protection

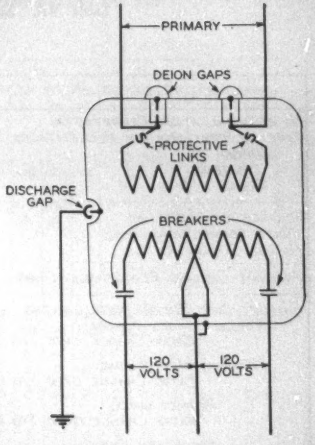


Figure 9 (right). Type CSP transformer

the data indicates some benefit of the tie with the tank. The common primary and secondary neutral seem to be about equally effective as the conventional interconnection. In rural areas the *SP* transformer ranks next to the solid interconnection schemes. In general it is believed that three-point protection ranks next. The gapped interconnection and the standard connection rank last. The gapped interconnection seems no better if as good as the standard connection. A possible explanation is that the impulse flashover of the gaps used may be as high as the bushing flashover voltages. If the secondary bushings flashover on a transformer protected

Table VI (Continued). Summary of Operating Data by Company and by Year

Solid Interconnection Obtained by Common Primary and Secondary Neutral—Figure 6

	L5			L8			Z0	Z1			Z8				Z1	Z2				Z3	Z9				S1			S6	T0		
	Ave.	1935	1936	Avg.	1935	1936	Avg.	1935	1936		Avg.	1934	1935	1936	Avg.	1936	1935	1936			Avg.	1936	1936			Avg.	1935		Avg.	1936	1934		Avg.
734	16.24	1000	1000	1000	733	1539	1166	2020	4600	4835	3ª	4719	434	433	444ª	111ª	481	2847	7230	5120	1378	1182	7365	494	2°	80°	503ª	585	2078	3635	3716	2830	210	63	243
100		100	100	100	100	100	100	100	95 13 0	100	100	100	100	100	100	100	100	98.0	70 20 10	100	100	100	100	12.4 0 87.6	100	100	100	100	100	36.3 0 63.7	100	100	100	79.8 20.2
4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	2Δ Δ Line	4 Y 240 Line	4 Y 240 Line	4 Y 240 Line	4 Y 240 Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y Line	4 Y 240 Line	4 Y 240 Line	4 Y 240 Line	4 Y 240 Line	2.3 Δ 4 Y Line	12 Y Line	12 Y Line	12 Y Line	12 Y Line	4 Y 240 Trans	12 Y 240 Trans	240 Trans	4 Y Line	4 Y 240 Line	4 Y 240 Line	4 Y 240 Line
20-	20-				3	0.5-			21	0241			10	10	10	10	10		1.0	0.7	1.0	1.5	1.0	30	17	17	17	17		20	2.0	0*			
2.12 53.6	1.23 64.7	1.78 41.2	3.00 33.8	2.39 ſ	1.01 ſ	0.52 62.7	0.69 53.7	1.14 74.0	0.41 9.0	0.41 ſ	0 ſ	0.41 10.1	0.23 ſ	0 *	0 0	0 0	0.07 1.74	0.84 ∞	0.32 ſ	0.10 ſ	0.25 ſ	0.42 ſ	0.24 ſ	3.04 46.4	100	6.25 ſ	2.78 ſ	3.39 41.5	2.89 ſ	9.12 ſ	6.85 ſ	0 ſ	0.95 6.14	3.77 55.8	1.52 11.7
0.13 36.2	0.03 14.5	0.38 ∞	1.17	1.08	0.25 ſ	0.39 54.0	0.30 42.3	0.05 20.0	0.07 1.5	0.02 ſ	0 ſ	0.04 6.17		0 *	0 0	0 0	0 0	0.46 1.28	0.14 ſ	0.04 ſ	0.13 ſ	0.17 ſ	0.11 ſ	0.41 77.3	0 0	0 0	0.40 97.7	0.34 23.6	0.05 ſ	0.27 ſ	0.19 ſ	0 ſ			
0 0	0 0				0.23 ſ	0.33 66.0	0.30 18.7		0.04 ∞	0.02 ſ	0 ſ	0.03 ∞		0 *	0 0	0 0	0 0		0.04 ſ	0.02 ſ	0 ſ	0.08 ſ	0.03 ſ		0 0	0 0	0.20 12.3	0.17 27.2	0.05 ſ	0.14 ſ	0.11 ſ	0 ſ			
0 0	0 0				0 ſ	0 0	0 0		0.02 ∞	0 ſ	0 ſ	0.01 ∞		0 *	0 0	0 0	0 0		0 ſ	0 ſ	0 ſ	0 ſ	0 ſ		0 *	0 *	0 *	0 0	0 ſ	0 ſ	0 ſ	0 ſ			
0.13 86.6	0.03 32.0				0 ſ	0 0	0 0		0 0	0 ſ	0 ſ	0 0		0 *	0 0	0 0	0 0		0.10 ſ	0.02 ſ	0.13 ſ	0.08 ſ	0.07 ſ		0 0	0 0	0.20 80.0	0.17 34.5	0 ſ	0.14 ſ	0.09 ſ	0 ſ			
0.27 87.0	0.09 49.2	0 *	0.06 ∞	0.03 10.7					0.08 ∞	0.04 ſ	0 ſ	0.04 1.25	0.46 ſ	0 *	0.45 300	0 0	0.28		0.70 ſ	0.39 ſ	0.93 ſ	1.89 ſ	0.69 ſ						0.24 ſ	0.41 ſ	0.35 ſ	0 ſ			
									0 *	0.02 ſ	0 ſ	0.11 ∞	1.62 ſ						0.29 ſ						0 *	0 *	0 *	0 *	0 ſ	0.16 ſ	0.11 ſ	0 ſ			
									0 *	0 ſ	0 ſ	0 *	0 ſ						0.33 ſ										0 ſ	0 ſ	0 ſ	0 ſ			
No	No	No	No	No	No	Some		No	No	Yes	Yes			Some	Yes	Yes		No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No

a. Rural type transformers using spill gap b. Includes Fig. 3 c. Horn gap instead of L.A.

Table VII. Summary of Operating Data by Company and by Year

Surge-Proof Transformer—Figure 7

Company	1			3	4								7			
Year	1934	1935	Avg.	1936	1935				1936			Avg.	1934	1935	1936	Avg.
No. of Installations Reported On	60	150	105	32	27	255	16	1	4	120	56	418	449	551	672	672	632
Type of Territory by Percentages																	
Urban				100	13	91	12			100							
Suburban					0	18	50				100		100		10		100
Rural	100	100	100		87	81	38	100	100			100		100	90		
Voltage of System - KV	4.4	12.5	4.4	12.5	4.4	12.2	4.4	7.6	13	2.3-13	2.3-13	2.3-13			24.4	4	
Phase Connection	Y	Y	Y	Y	Δ	Δ	Y	Δ	Δ	ΔY	ΔY	ΔY		✓	Y	Y	
Fusing Schedule - %										250	250	250					
Average Ground Resistance - Ohms	20	15	16.4		83	120	3	150	180	50	75	100		95.6	150		
Failure Data Per 100 Installations																	
Primary Fuses Blown	0	0.67	0.49	37.5	3.70	3.14	0	0	25.0	5.83	46.5	9.80	9.36	9.78	11.0	15.32	18.10
Ratio - Change over Std. Connection - %	0	17	5.65	688	7.60	6.42	0	0	27.9	14.5	594	31.7	77.9	91.9	82.7	93.0	106
Transformer Winding	0	0	0	0	3.70	0	0	0	0	0.83	0	0.48	0.45	0.18	0.30	0	0.32
Ratio Change over Std. Connection - %	0	0	0		53.5	0	0	0	0	134	0	18.4	34.0	35.4	37.7	0	41.2
Primary Only	0	0	0	0	3.70	0	0	0	0	0	0	0	0.11		0.15	0	0.07
Ratio Change over Std. Connection - %		0			111	0	0	0	0	0	0	0	15.6		130		
Secondary Only	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Ratio Change over Std. Connection - %		0			0	0	0	*	0	0	0	0	0		0		
Primary & Secondary	0	0	0	0	0	0	0	0	0	0.83	0	0.48	0.39		0.15	0	0.30
Ratio Change over Std. Connection - %		*			0	0	0	0	0	6.15	0	30.0	36.6		93.7		
Deion Gap	0	0	0	0	0	0.78	0	0	0	0	0	0.72	0.56	1.39	1.48	3.28	2.96
Ratio Change over Std. Connection - %	0	0	0		0	10.0	0	0	*	0	0	26.2	68.0	60.2	36.2	111	102
Customers' Meters Burned Out	0	0	0		0	0	0	0	0	0	1.79	0	0.11				
Ratio Change over Std. Connection - %	0	0	0		0	0	0	*	*	0	2.71	0	4.70				
Customers' Wiring, Etc. Damaged	0	0	0		0	0	0	0	0	0.83	0	0	0.11		0.15	0.30	0.22
Ratio Change over Std. Connection - %	*	*			0	0	0	*	*	17.7	0	0	27.1		10.7	∞	16.7
Cover Removal After Fuse Failure To Inspect Gaps	No	Yes			Yes	Some	No		No	50%	50%	50%		Yes	Yes	Yes	Yes

Company	23				24			25	29	33				34			
Year	1934	1935	1936	Avg.	1934	1936	Avg.	1934	1934	1934	1935	1936	Avg.	1934	1935	1936	Avg.
No. of Installations Reported On	5	5	5	5	5	528	267	8	18	96	138	141	125	14	11	11	12
Type of Territory by Percentages																	
Urban		0	60			97					14	13.5	10.1	100	100	100	100
Suburban		60	0	100			100	100	100		0	0	0				
Rural	100	40	40		100	3				100	86	86.5	89.9				
Voltages of System - KV		2.4-4	2.3-4			2.4-6.9				2.4-6.6	2.4-6.6	2.3-12		2.4	2.4	2.4	2.4
Phase Connection		Y-Y	ΔY			Y-Δ				ΔY	ΔY	ΔY		Δ	Δ	Δ	Δ
Fusing Schedule - %	200	200	200	200		240								240	240	240	240
Average Ground Resistance - Ohms	20				20	25	25	12				30					
Failure Data Per 100 Installations																	
Primary Fuses Blown	20	0	0	6.67		2.27	2.27		0	2.09	0	7.10	3.12	0	9.09	9.09	5.55
Ratio Change over Std. Connection - %	1739	0	0	368		121	137		0	15.4	0	108	26.8	0	2330	123	144
Transformer Winding	0	0	0	0	0	2.08	2.06	0	0	0	0	0.71	0.27	0	0	9.09	2.78
Ratio Change over Std. Connection - %	*	0	*	0	†	195	211		0	0	0	134	41.0	0	0	1750	602
Primary Only	0	0	0	0	0					0	0		0	0	0	0	0
Ratio Change over Std. Connection - %	*	0	*		†										0	0	0
Secondary Only	0	0	0	0	0					0	0		0	0	0	0	0
Ratio Change over Std. Connection - %	*	0	*		†										*	0	0
Primary & Secondary	0	0	0	0	0					0	0		0	0	0	9.09	2.78
Ratio Change over Std. Connection %	*	0	*		†										0	2270	1080
Deion Gap	0	0	0	0	0			0	0	0				0	0	9.09	2.78
Ratio Change over Std. Connection %	0	0		0	†				0					*	0		1080
Customers' Meters Burned Out	0	0	0	0	0	0	0	0	0	0							
Ratio Change over Std. Connection - %	*	0		0	†				0								
Customers' Wiring, Etc. Damaged	0	0	0	0	0	0	0	0	0	0							
Ratio Change over Std. Connection - %	*	*		*	†				0								
Cover Removal After Fuse Failure To Inspect Gaps	Yes	Yes	Yes	Yes	No	Yes		No	No	No	No	No	No	No	No	No	No

Table VII (Continued). Summary of Operating Data by Company and by Year

Surge-Proof Transformer—Figure 7

9°						14				15				16	17				19				21			22		
1934	1936				Avg.	1934	1935	1936	Avg.	1934	1937	1936	Avg.	1934	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1935	1936	Avg.	1934	1936	Avg.
99	534	230	511	96	745	11	11	16°	13	591	1051	1262	968	80	12	13	16	14	29	30	30	30	3	3	3	50	45	48
	70	0	10	10	} 100							5											100	100	100		33.3	
	30	20	20	20																							11.1	} 100
	0	80	70	70		100	100	100	100	} 100	} 100	95			100	100	100	100	100	100	100	100				100	55.6	
	23	3848	5411.5	1488		4.8	4.8	4.8	4.8	4	4	4	4		12	12	12	12		2.4	2369		4	4	4		6.9	
	Δ	ΔtY	ΔtY	Δ		Δ	Δ	Δ	Δ	Y	Y	Y	Y		Y	Y	Y	Y		Δ	Δ		Y	Y	Y		Δ	
	230	230	230	230	230	300	300	300	300						200	200	200	200					240	240	240		240	
200						66.5	72	64	68					25	10.5	15			43							10	7	8.5
1.01	0	0	0	0	0.07	9.10	27.3	31.2	23.7	0.34		2.30	1.62	0	16.67	13.30	12.50	13.95	13.70	13.30	6.67	11.25	0	0	0	0	20.0	9.48
2.00					0.16	46.4	135	97.5	108	4.45		31.6	22.9		487	161	258	531	156	249	62.0	168	0	†	0		97.0	56.9
0	0		0.89	2.08	0.32	0	0	0	0	1.01	0.38	0.40	0.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0					10.5	0	*	*	0	29.2	∞			0	0	0	0	0	0	0	0	0	0	†	0	0	0	0	0
0	0					0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							*	*			*					0	*						*	†	*		0	
0	0					0	0	0	0		0.19	0.08	0.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							*	*			∞					0	*						*	†	*		*	
0	0					0	0	0	0		0.19	0.32	0.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							*	*			∞					0	0						0	†	0		0	
K.16	0.18	1.30			2.29	0	0	0	0	3.05	0.38	0.47	0.97		16.67	0	0	4.63	3.45	0	0	1.13	0	0	0	0	0	0
	2.86				49.8		0	*		92.5	∞	∞	34.5		4900	0	0	1191	392	0	0	314	*	†	0			
0						0	0	0	0					0	0		0	0	0	0		0	0	0	0			
							0	*						*	0		*	0	*	*		0	*	†	*			
0						0	0	0	0						0		0	0	0	0		0	0	0	0	0		
							*	*							0			0	0	*		0	*	†	*	0		
Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No		No	No	No	No		Yes	Yes‡	No		No	No	No	No		Yes		No	No	No

36				42	30						39	70		
1934	1935	1936	Avg.	1935	1935	1936				Avg.	1936	1936		Avg.
71	140	140	117	76	79	18	4	4	9	64	69	8	10	13	23
					100	33	100			100					
} 100	100	100	} 100			67		100	100		} 100			100	
	4	4		4-12	2.4	6.6	12	12	12	4		6.9	12	6.9	
	Y	Y		Y	Y	Y	Y	Y	Y	Y		Δ	Y	Δ	
	240	240					240	240	240	240			200		
2.0	25	0.2	10.4		17	17						2.8		15	
0	0	0	0	18.4	0	0	250	250	0	9.38	4.50	0	10.00	0	4.95
0	0	0	0	4.69	0	0				308	52.0	0	6.45	0	53.4
0	0	0	0	0	1.27	0	0	0	0	0	0.36	0	0	0	0
	0	0	0	0	90.9	0	0	0	0	0	58.5	0			
0	0	0	0	0	1.27	0	0	0	0	0	0.56	0	0	0	0
				0	116	0	0	0	0	0	93.7				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	*	0	0	0	0	0				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0				
0	0	0	0		0	0				0	0	0	0	0	0
	0	0	0		0	0									0
0	0	0	0		0	0				0	0	0	0	0	0
	0	0	0		*	*				*	*	0			0
0	0	0	0		0	0				0	0	0	0	0	0
	0	*	0		*	*					*				
	Yes			Yes			No	No	No	No	No	No	No	No	No

* No failures either connection.
† Standard Connection not used.
a. Includes Type C.S.P. Transformers.
b. Data on units subject to most lightning surges.

Table VIII. Summary of Operating Data by Company and by Year

Three-Point Protection—Figure 8

Company	4				7				18				22	24	25	33				42	50		
Year	1933	1934	1936	Avg.	1934	1935	1936	Avg.	1934	1935	1936	Avg.	1934	1936	1936	1934	1935	1936	Avg.	1935	1935	1936	Avg.
No. of Installations Reported On	723	234	58	130	573	62	50	110	60	50	111		20	19	19	19	100	350	20	22	69	19	33	14	213	314	264
Type of Territory by Percentages																											
Urban	47	100																100									
Suburban	20		100		100									100	100		100		100						100	100	100
Rural	33			100		100	100	100	100	100	100	100	100			100				100	100	100	100				
Voltage of System - kV	2.4	2.4/4.2	2.4/4.2	2.4/4.2	4	4	4	4	4	4	4	13.2	13.2	13.2	13.2		2.4/4.8			6.6	6.6/11.4			4.16	4	4	4
Phase Connection	Δ	Δ	Δ	Δ	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y-Δ&Δ			Δ	ΔorY			Y	Y	Y	Y
Fusing Schedule - %	220	220	220														200										
Position L.A With Respect To Fuse	Both	Both	Both	Both	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Both	Line			Both	Both	Both	Both				
Average Ground Resistance - Ohms	17.5	7	10	20		80	21	70					3	3	3	3	10		12			30		17			
Failure Data Per 100 Installations																											
Primary Fuses Blown	3.60	1.28	20.7	1.54	3.76	11.30	6.00	15.50	14.67	28.0	15.35	5	5.27	15.50	8.62					0	0	0	0	0	1.27	1.27	
Ratio Change over Std Connection-%	740	36.2	264	498	30.1	106	56.3	197	317.4	164	198	1	1	34.2	730					0	0	0	0	0	41.6	14.7	
Transformer Winding	0.37	0.43	3.45	1.54	1.05	0	0	0	0	0	0	3	0	0	1.73		0		0	0	0	0	0	0	0	0	
Ratio Change over Std Connection-%	156	73.6	363	390	82.1	0	0	0	0	0	0	1	1	0	243		0			0	0	0	0	0	0	0	
Primary Only	0.63	0.43	0	0.77	0.61	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	
Ratio Change over Std Connection-%	20.7	12.7	0	80.2	16.2			0					1	0	0					0				0	0	0	
Secondary Only	0.14	0	17.2	0	0.17	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	
Ratio Change over Std Connection-%	11.7	0	1432	0	57.9			0					1	*	0					0				0	0	0	
Primary & Secondary	0.16	0	17.2	0.77	0.26	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	
Ratio Change over Std Connection-%	13.0	0	338	80.2	43.6			0					1	*	0					0				0	0	0	
Lightning Arrester	1.25	0.43	6.90	0	1.22	12.8	6.00	19.10	8.33	20.0	14.15	0								0	0		0				
Ratio Change over Std Connection-%	16.1	18.9	1046	0	14.9	338	182	446.5	282	677	490	1															
Customers' Meters Burned Out	0	0.43	0	0	0.09				0	0		0								0	0		0	0	0	0	
Ratio Change over Std Connection-%	0	85.6	0	0	37.2							1												*	*	*	
Customers' Wiring, Etc. Damaged	0	1.71	0	0.77	0.35			0.31				0								0	0		0	0			
Ratio Change over Std Connection-%	0	34.4	0	46.0	95.4			65.0				1												*			

* No failures either connection
† Standard Connection not used.

by the standard connection, the effect is similar to the action of a gapped interconnection on three-point connection. This may explain why the three-point connection, the gapped interconnection, and the standard connection show similar operating results. It is also interesting to note that the relative performance of the various schemes of protection do not align in their expected relative order of merit when data on urban and suburban installations are compared. Of the 19 companies reporting data on type *CSP* transformers three state that they install primary fuses with them. Of 11 companies reporting data on type *CSP* transformers only one states that an increase in branch fuses blown was noted.

Table IX. Summary of Operating Data by Company and by Year

Type CSP Transformer—Figure 9

Company	1	2	4											5	6*			7			12			16		
Year	1933	1936	1934	1935							1936		Avg.	1934	1935	1936	Avg.	1936	1936	Avg.	1935	1936	Avg.	1935	1936	Avg.
No. of Installations Reported On	23	41	176	11	139	18	5	24	11	34	56	31	188	236	349	17	26	1	44	361	598	480	330	421	396	1.42	733	508
Type of Territory by Percentages																												
Urban		100		10	23	17			14	3	100									25						30	20	
Suburban			100	0	26	28			21	9		100		100		34	100			75			100	100	100	40	30	100
Rural	100			90	51	55	100	100	65	88			100		100	6		100	100							30	50	
Voltage of System - kV	2.4/4.2	4.16	2.4	2.6	4	6.6		11	13	24-33	24-33	24-33				4	4	4	4	2.4/4.8	4.8	2.4/4.8	4	4	4	4.8-6.6	2.3-4.3	
Phase Connection	Y	Y	Δ	Δ	Y	Δ	Δ	Δ	ΔorY	ΔorY	ΔorY	ΔorY				Y	Y	Y	Y	ΔorY	Y	ΔorY	Y	Y	Y	Δ	ΔorY	
Average Ground Resistance - Ohms	8		42.5		65	5		25.0	35	25	4	20	80		5	25.0	25.0	25.0	25.0							20		
Failure Data Per 100 Installations																												
Primary Fuses Blown	0	0	4.53	0	0	0	0	0	9.09	0	0	0	0.53	1.41	0	0	0	0	0	0	0	0		0	0			
Ratio Change over Std Connection-%	0	0	48.7	0	0	0	0	0	10.1	0	0	0	1.72	10.7		0	0	0	0	0	0	0		0	0			
Transformer Winding	0	0	0	0	0	5.33	0	0	9.09	0	0	0	0	0.28	0	0	0	0	0	0	0	0	0	0.71	0.29	0.76	0.38	0.69
Ratio Change over Std Connection-%	0	0	0	0	0	83.2	0	0	92.8	0	0	0	0	21.6		0	0	*	0	0	0	0	*			153	93.0	69.0
Primary Only	0	0	0	0	0	5.33	0	0	0	0	0	0	0	0.141	0	0	0	0	0	0	0	0	0	0	0	0		
Ratio Change over Std Connection %	0				0	16.7	0	0	0	0	0	0	0	19.9		*	*	*	*	0			0			0		
Secondary Only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0.13	0		
Ratio Change over Std Connection %	0				0	0	*	0	0	0	0	0	0	0		*	0	*	0	0			*			0		
Primary & Secondary	0	0	0	0	0	0	0	0	9.09	0	0	0	0	0.14	0	0	0	0	0	0	0	0	0	0.47	0.26	0.76		
Ratio Change over Std Connection %	*				0	0	0	0	82.2	0	0	0	0	23.6		0	0	*	0	0			*					
Deion Gap	0	0	0	0	0	5.33	0	0	9.09	0	0	0	0	0.28		0	*	0	0	0	0	0	0	0	0	0		
Ratio Change over Std Connection %	0		0	0	0	71.4	0	*	∞	*	0	0	0	54.4		*	*	*	*	0			*	*	0	0		
Customers' Meters Burned Out	0		1.14			0	0	0	0	0	0	0	0.53	0.42	0	0				0							0	0
Ratio Change over Std Connection %	0		1036			0	0	*	*	*	0	0	4.49	18.08		0				0							*	*
Customers' Wiring, Etc. Damaged	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.85	0	2.27	0.28	0.17	0.21					0	0
Ratio Change over Std Connection %	*		0	0	0	0	0	*	*	*	0	0	0	0		*	1400		1235	200	54.8	156					*	
Increase In Tap or Branch Fuses Blown	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No								

* No failures either connection
† Standard Connection not used.

a. Includes approx 10 Surge-Proof Transf's. b. Not directly comparable with Fig 1. c. Transf's equipped with one bushing and one gap.

In comparing the relative merit of the various schemes of protection in reducing *transformer winding failures* a study of tables X to XV indicates conflicting trends which make it difficult to draw definite conclusions. If rural installations only are considered the *CSP* transformer shows the best performance with the common primary and secondary neutral system next with the *SP* transformers, the three-point connection, the standard connection, the gapped interconnection, and the solid interconnection following in the order listed. However, when urban and suburban installations are considered almost the reverse trend is noted in that the various types of solid interconnection show the best performance with the *CSP* transformer, the *SP* transformer, the three-point connection, the gapped interconnection, and the standard connection following in that order. This lack of consistency may be due to the fact that in all cases the rate of transformer-winding failures is so small that there is less probability of distinct trends being established without collecting data over a number of years. Moreover the age and design of the transformer, the number of lightning surges to which it has been previously exposed, the degree of exposure, and isokeraunic level all affect the probability of transformer failure. The fact that *SP* and *CSP* transformers are both relatively new and of more modern design is undoubtedly at least in part a contributing factor in their good performance as well as the protection scheme used on them. It is interesting to note that in both methods of comparison that the three-point connection, the standard connection, and the gapped interconnection are all grouped together possibly for the same reason that was discussed under rates of primary fuses blown. In comparing the performance of rural installations it is difficult to explain the difference in the performance of the common neutral system and the solid interconnection as they are essentially the same in so far as lightning protection is concerned. It is believed that it is safe to conclude that the newer schemes are better than the standard connection but with little to choose between the three-point connection, the gapped interconnection, and the standard connection.

In considering the effect of the various methods of protection on the *rate of arrester failures* the data are somewhat conflicting but show that the *CSP* transformer and the several methods of solid interconnection have the lowest failure rates. The three-point connection consistently shows the maximum failure rate. However, this may be due to the small number of installations and the fact that most of them were protected by a type of arrester with a known high failure rate. Since the type of arrester has a considerable bearing upon the failure rate, definite conclusions cannot be drawn relative to the effect of the type of protection scheme used. However, since the failure rates for solid interconnections are not higher than those for the standard connection, it can be concluded that the fear that has been expressed that with solid interconnection a heavier duty may be placed on the arrester causing more failures is without foundation. Since in case of type *SP* transformers a deion-gap failure cannot be noted unless the top of the transformer tank is removed and an examination made, the practice of the companies as to this point was determined. Of 17 companies reporting this point on type *SP* transformers, seven reported that the tank covers are removed after primary fuses are blown. Unless this is done gap failures may not be observed.

Table IX (Continued). Summary of Operating Data by Company and by Year

Type CSP Transformer—Figure 9

17				18			21			22			23			24	25	38			40	42	44	45	50			62	66			69			72		
1933	1936		Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1935	1935	1936	Avg.	1935	1935	1935	1936	1935	1936	Avg.	1936	1935	1936	Avg.	1935	1936	Avg.	1936		Avg.
4	4	4	6	14	44	7	39	4	4	4	135	38	118	145	6.54	400	5	5	39	39	39	89	9	10	1538	74	132	103	43	50	80	80	1	1	1	8	38	46
100	100		66.7	100	100	100	100	100	100	100	0	236	100	100	1.8	1.5	100	100	100	100	100	39			20	42	228	100	100				100	100	100	97.5		100
		100	33.3			100					40	133		100	98.2	98.5						17		100	0	38	24.2								62.5	100	
											40	49.1										2.4			60	38	33.0										
4 Y	4 Y	12 Y	4 1/2 Y	4 Y	4 Y	132 Y		4 Y	4 Y	4 Y	6.6 Δ	6.9 Δ	6.9 Δ	24-12 Δ Y	23-12 Δ Y	23-12 Δ Y	2.4 Δ	4 Y	2.4 Δ	2.4 Δ	2.4 Δ	4 Y	4.12 Y	4 Y	2.3-6.3 Δ	6.6 Y	12 Y	6.9-12 Y	6.9 Δ	23-13 Y	4-138 Δ Y	23-138 Δ Y	4.8 2-Ø	4.8 2-Ø	4.8 3-Ø	23-12 Δ Y	6.9 Δ	
13				3	3	3	3	15			15			30			25		15-38			2		13		17			28	10	10	10				15		
0	0	0	0	0	0	143	1.94	0	0	0		0		0	0.76	0.63	0	0	0	0	0	0	0	0	0			0	0			0	0	0		0	0
0	0	0	0	1	0	910	134	0	1	0		0		0	11.6	5.38	0	0	0	0	0	0	0	0	0			0	0			0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.65	0	0	0	0	1	1	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
25				0	0	0	0	0	0	0	0	0	0	0.46	0.46	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0		0	0
4,320				1				4	1	4							0	0	0	0	0	0	0	0	33.3	0	0	0	0	1	1	1	0	0	0			
	0	0	0					0	1	0							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
	0	0	0					4	1	4							0	0	0	0	0	0	0	4	0	4	4	4	0	1	1	1	4	4	4			
		0	0					4	1	4							0	0	0	0	0	0	0	4	0	4	0	0	0	1	1	1	4	4	4		0	0
		No	No	No						No				No					No			No		No			No	No	No	No	4	No	No	No	No	•	No	

d. Decrease noted. e. Increase noted on urban installations

Table VIII. Summary of Operating Data by Company and by Year

Three-Point Protection—Figure 8

Company	4				7				10				22	24	25	33				42	50			
Year	1933	1934		Avg	1934	1935	1936	Avg	1934	1935	1936	Avg	1934	1935	1936	1934	1935	1936	Avg	1935	1935	1936	Avg
No. of Installations Reported On	723	234	58	130	573	62	50	110	60	50	111		20	19	19	19	100	350	20	22	69	19	33	14	2.13	314	264
Type of Territory by Percentages																											
Urban	47	100															100										
Suburban	20		100		100									100	100				100						100	100	100
Rural	33			100		100	100	100	100	100	100	100	100			100				100	100	100	100				
Voltage of System - KV	2.4	2.4/4.8	2.4/4.8	2.4/4.8	2.4/4.8	4	4	4	4	4	4	4	13.2	13.2	13.2	13.2		2.4/4.8		-	6.6	6.6/11.5		M.12	4	4	4
Phase Connection	Δ	Δ	Δ	Δ	Δ	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		M.&W			Δ	ΔtY		Y	Y	Y	Y
Fusing Schedule - %		250	250	250														200									
Position LA With Respect To Fuse	Beh	Bef	Bef	Bef	Beh	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line		Line		Beh	Bef	Bef	Bef				
Average Ground Resistance - Ohms	175	7	10	20		60	21	70					3	3	3	3	10		12			36			17		
Failure Data Per 100 Installations																											
Primary Fuses Blown	3.60	1.28	20.7	1.54	3.76	11.30	6.00	13.50	16.67	28.0	15.35		5*	5.27	15.80	8.62				0	0	0	0	0		1.27	1.27
Ratio Change over Std Connection-%	740	26.2	264	4.98	30.1	106	56.3	137	317.4	164	198		1	1	34.2	780				0	0	0	0	0		41.6	14.7
Transformer Winding	0.97	0.43	3.45	1.54	1.05	0	0	0	0	0	0		3	0	0	1.73	0		0	0	0	0	0	0	0	0	0
Ratio Change over Std Connection-%	15.6	19.6	363	39.0	82.1	0	0	0	0	0	0		1	1	0	24.9	0		0	0	0	0	0	0	0	0	0
Primary Only	0.69	0.43	0	0.77	0.61	0	0	0	0	0	0			0	0	0	0		0	0	0	0	0	0	0	0	0
Ratio Change over Std Connection-%	20.7	12.7	0	80.2	86.2			0						1	0	0					0	0	0	0	0	0	0
Secondary Only	0.14	0	1.72	0	0.17	0	0	0	0	0	0			0	0	0	0		0	0	0	0	0	0	0	0	0
Ratio Change over Std Connection-%	11.7	0	143.2	0	57.9			0						1	*	0					0	0	0	0	0	0	0
Primary & Secondary	0.14	0	1.72	0.77	0.26	0	0	0	0	0	0			0	0	0	0		0	0	0	0	0	0	0	0	0
Ratio Change over Std Connection-%	13.0	0	358	80.2	43.6			0						1	*	0					0	0	0	0	0	0	0
Lightning Arrester	1.25	0.43	6.90	0	1.22	12.8	6.00	19.10	8.33	20.0	14.15		0							0	0		0				
Ratio Change over Std Connection-%	16.1	18.9	1046	0	14.9	398	182	446.5	282	677	430		1														
Customers' Meters Burned Out	0	0.43	0	0	0.08				0	0			0							0	0		0		0	*	0
Ratio Change over Std Connection-%	0	85.6	0	0	3.72								1												*		*
Customers' Wiring, Etc. Damaged	0	1.71	0	0.77	0.35			0.51					0							0	0		0		0		
Ratio Change over Std Connection-%	0	34.4	0	14.0	85.4			6.50					1												*		

* No failures either connection
† Standard Connection not used.

by the standard connection, the effect is similar to the action of a gapped interconnection on three-point connection. This may explain why the three-point connection, the gapped interconnection, and the standard connection show similar operating results. It is also interesting to note that the relative performance of the various schemes of protection do not align in their expected relative order of merit when data on urban and suburban installations are compared. Of the 19 companies reporting data on type *CSP* transformers three state that they install primary fuses with them. Of 11 companies reporting data on type *CSP* transformers only one states that an increase in branch fuses blown was noted.

Table IX. Summary of Operating Data by Company and by Year

Type CSP Transformer—Figure 9

Company	1	2	4										5	6*			7			12			16		
Year	1933	1936	1934			1935					1936		Avg	1934	1935	1936	Avg	1931	1936	Avg	1935	1935	Avg	1935	1936	Avg
No. of Installations Reported On	23	41	176	11	133	18	5	24	11	34	56	31	188	236	34*	17	36	1	22	361	596	480	380	421	396	242	733	308
Type of Territory by Percentages																												
Urban		100		10	23	17			14	5	100									23						80	20	
Suburban			100	0	26	28			21	9		100		100		94	100			73			100	100	100	60	30	100
Rural	100			90	51	55	100	100	65	86			100		100	6		100	100							30	50	
Voltage of System - KV	2.4/4.2	4.8/2		2.4	2.8	4	6.6		11	13	24-33	24-66	24-111			4	4	4	4	2.4/4.8	4	4	4	44-66	23-43	
Phase Connection	Y	Y		Δ	Δ	Y	Δ	Δ	Δ	ΔtY	ΔtY	ΔtY	ΔtY			Y	Y	Y	Y	ΔtY	Y	ΔtY	Y	Y	Y	Δ	ΔtY	
Average Ground Resistance - Ohms	8		123		65	5		250	35	25	4	20	80		5	250	250	250	250							20		
Failure Data Per 100 Installations																												
Primary Fuses Blown	0	0	4.53	0	0	0	0	0	20.3	0	0	0	0.53	1.41	0	0	0	0	0	0	0	0		0	0			
Ratio Change over Std Connection-%	0	0	487	0	0	0	0	0	101	0	0	0	172	307		0	0	0	0	0	0	0		0	0			
Transformer Winding	0	0	0	0	0	5.53	0	0	30.9	0	0	0	0.28	0	0	0	0	0	0	0	0	0	0	0.71	0.29	0.76	0.98	0.69
Ratio Change over Std Connection-%	0	0	0	0	0	99.2	0	0	52.8	0	0	0	21.6			0	0	*	0	0	0	0	*			163	330	98.0
Primary Only	0	0	0	0	0	5.53	0	0	0	0	0	0	0.141	0	0	0	0	0	0	0	0	0	0	0	0	0		
Ratio Change over Std Connection %	0				0	16.7	0	0	0	0	0	0	19.9			*	*	*	*				0			0		
Secondary Only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0.19	0		
Ratio Change over Std Connection %	0				0	0	*	0	0	0	0	0	0			*	0	*	0				*			0		
Primary & Secondary	0	0	0	0	0	0	0	0	9.09	0	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0.47	0.26	0.76		
Ratio Change over Std Connection %	*				0	0	0	0	82.2	0	0	0	23.6			0	0	*	0				*			0		
Design Gap	0	0	0	0	0	5.53	0	0	9.09	0	0	0	0.28			0	0	0	0	0	0	0	0	0	0	0		
Ratio Change over Std Connection %	0		0	0	0	71.4	0	*	∞	*	0	0	54.4			*	*	*	*	0	0	0	*	*	0	0		
Customers' Meters Burned Out	0		1.14		0	0	0	0	0	0	0	0	0.39	0.42	0	0				0							0	0
Ratio Change over Std Connection %	0		103		0	0	*	*	*	*	0	0	4.49	18.08		0				0							*	*
Customers' Wiring, Etc. Damaged	0		0	0	0	0	0	*	0	*	0	0	0	0	0	0	5.85	0	2.27	0.28	0.17	0.21					0	0
Ratio Change over Std Connection %	*		0	0	0	0	*	*	*	*	0	0	0	0		*	1480		1235	200	54.8	156					*	
Increase In Tap or Branch Fuses Blown	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No							

* No failures either connection
† Standard Connection not used.

a. Includes approx 10 Surge-Proof Transf's. b. Not directly comparable with Fig 1. c. Transf's equipped with one bushing and one gap.

In comparing the relative merit of the various schemes of protection in reducing *transformer winding failures* a study of tables X to XV indicates conflicting trends which make it difficult to draw definite conclusions. If rural installations only are considered the *CSP* transformer shows the best performance with the common primary and secondary neutral system next with the *SP* transformers, the three-point connection, the standard connection, the gapped interconnection, and the solid interconnection following in the order listed. However, when urban and suburban installations are considered almost the reverse trend is noted in that the various types of solid interconnection show the best performance with the *CSP* transformer, the *SP* transformer, the three-point connection, the gapped interconnection, and the standard connection following in that order. This lack of consistency may be due to the fact that in all cases the rate of transformer-winding failures is so small that there is less probability of distinct trends being established without collecting data over a number of years. Moreover the age and design of the transformer, the number of lightning surges to which it has been previously exposed, the degree of exposure, and isokeraunic level all affect the probability of transformer failure. The fact that *SP* and *CSP* transformers are both relatively new and of more modern design is undoubtedly at least in part a contributing factor in their good performance as well as the protection scheme used on them. It is interesting to note that in both methods of comparison that the three-point connection, the standard connection, and the gapped interconnection are all grouped together possibly for the same reason that was discussed under rates of primary fuses blown. In comparing the performance of rural installations it is difficult to explain the difference in the performance of the common neutral system and the solid interconnection as they are essentially the same in so far as lightning protection is concerned. It is believed that it is safe to conclude that the newer schemes are better than the standard connection but with little to choose between the three-point connection, the gapped interconnection, and the standard connection.

In considering the effect of the various methods of protection on the *rate of arrester failures* the data are somewhat conflicting but show that the *CSP* transformer and the several methods of solid interconnection have the lowest failure rates. The three-point connection consistently shows the maximum failure rate. However, this may be due to the small number of installations and the fact that most of them were protected by a type of arrester with a known high failure rate. Since the type of arrester has a considerable bearing upon the failure rate, definite conclusions cannot be drawn relative to the effect of the type of protection scheme used. However, since the failure rates for solid interconnections are not higher than those for the standard connection, it can be concluded that the fear that has been expressed that with solid interconnection a heavier duty may be placed on the arrester causing more failures is without foundation. Since in case of type *SP* transformers a deion-gap failure cannot be noted unless the top of the transformer tank is removed and an examination made, the practice of the companies as to this point was determined. Of 17 companies reporting this point on type *SP* transformers, seven reported that the tank covers are removed after primary fuses are blown. Unless this is done gap failures may not be observed.

Table IX (Continued). Summary of Operating Data by Company and by Year

Type CSP Transformer—Figure 9

17				18			21			22			32			34	36	38			40	42	44	45	50			55	66			69			72		
1935	1936		Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1936	Avg.	1935	1935	1935	1936	Avg.	1935	1935	1936	1936	1936	1936	Avg.	1936	1935	1936	Avg.	1936	1936	Avg.	1936	Avg.
4	4	6	14	44	7	39	4	4	4	133	38	118	140	6.04	4.00	3	5	39	39	39	83	9	10	1338	74	152	103	43	50	50	50	1	1	1	8	38	46
100	100	64.7	100	100	100	100	100	100	100	0	39.6	11.8	100			100	100	100	100	100	39			20	42	22.8	100	100				100	100	100	97.5	100
		33.3								40	13.3	0		98.2	98.5						17		100	0	0	24.2								62.5	
										60	47.1	98.5									2.4			60	58	53.0									
4	4	12	44.2	4	4	132		4	4	6.6	6.9	6.9	24.6	23.12	23.12	2.4	4	2.4	2.4	2.4	4	4.12	4	2.963	6.6	12	6.962	6.9	29.13	4.1-38	29.88	4.8	4.8	4.8	23.12	6.9	
Y	Y	Y	Y	Y	Y	Y		Y	Y	Δ	Δ	Δ	ΔδY	ΔδY	ΔδY	Δ	Y	Δ	Δ	Δ	Y	Y	Y	Δ	Y	Y	Y	Δ	Y	ΔδY	ΔδY	2wire	2wire	2wire	ΔδY	Δ	
18				3	3	3	3	15		15			30			2.5		13-38			2		13		17			28	10	10	10				15		
0	0	0	0	0	0	143	1.54	0	0	0			0	0.76	0.63	0	0	0	0	0	0	0	0	0				0	0			0	0	0		0	0
0	0	0	0	1	0	3.10	134	0	1	0			0	11.6	5.38	0	0	0	0	0	0	0	0	0				0	0			0	0	0		0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	1	1	1	0	0	0		0	0
0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.65	0	0	0	0	1	1	1	0	0	0			
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0		0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0			
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0		0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	1	1	1	0	0	0			
25				0	0	0	0	0	1	0	0	0	0.45	0.46		0	0	0	0	0	0	0	0	0.07	0	0	0	0	1	1	1	0	0	0		0	0
14.30							0	1	0	0						0	0	0	0	0	0		0	33.3	0											
	0	0	0				0	1	0							0		0	0	0	0		0		0	0	0	0	1	1	1	0				0	0
	0	0	0				0	1	0							0		0	0	0	0		0		0	0	0	0	1	1	1	0				0	0
	No	No	No				No			No			No			No		No			No		No		No	No	No	d	No	No	No	No	No	No	*	No	

d. Decrease noted. e. Increase noted on urban installations

Table X. Combined Operating Data on Various Methods of Protecting Distribution Transformers From Lightning for 1934, 1935, and 1936

All Types of Territory

Type of Protection	Average Number Installations	Average Ground Resistance	Failures per 100 Installations				
			Primary Fuses Blown	Transformer Winding Failures	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	159,138	60.0	6.35	0.717	1.17	1.10	0.103
Solid interconnection**	146,738	13.2	1.85	0.350	0.551	1.01	0.079
Gapped interconnection	11,029	48.8	10.10	0.676	0.963	1.97	0.141
Three-point protection	769	34.8	5.22	0.590	3.92	0.054	0.364
Surge-proof transformer	3,164	58.2	5.38	0.43	1.21*	0.036	0.102

* Deion gaps damaged per 100 installations. ** Includes common-neutral type.

Table XI. Combined Operating Data on Rural Installations for Various Methods of Protecting Distribution Transformers From Lightning for 1934, 1935, and 1936

Type of Protection	Average Number Installations	Average Ground Resistance	Failures per 100 Installations				
			Primary Fuses Blown	Transformer Winding Failures	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	15,645	93.0	9.98	0.565	2.24	1.205	0.132
Solid interconnection*	5,738	19.1	6.26	1.04	0.680	0.352	0.137
Capped interconnection	9,020	45.3	10.95	0.730	0.965	2.04	0.080
Three-point protection	217	42.7	8.28	0.460	8.06	0	0.554
Surge-proof transformers	890	85.5	7.72	0.272	1.66**	0	0.056

* Includes common primary and secondary neutral. ** Deion gap failures.

Table XII. Combined Operating Data Upon Various Methods of Protecting Distribution Transformers From Lightning for 1934, 1935, and 1936

Urban and Suburban Installations

Type of Protection	Average Number Installations	Average Ground Resistance (Ohms)	Failures per 100 Installations				
			Primary Fuses Blown	Transformer Winding Failures	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	84,991	77.7	3.65	0.660	0.593	0.736	0.066
Solid interconnection*	80,235	9.1	0.989	0.204	0.192	1.45	0.099
Capped interconnection	1,270	56.7	6.62	0.455	0.451	1.16	1.19
Three-point protection			No urban or suburban installations in 1934				
Surge-proof transformers	221	33.4	9.25	0.453	0.153	0.167	0.168

* Includes common primary and secondary neutral. ** Deion gap failures per 100 installations.

While the data for *meters burned out* and *troubles on customers' premises* are not conclusive, it can be concluded that solid interconnection does not increase the probability of trouble on the customers' premises due to lightning.

Effect of Ground Resistance

Since the resistance of lightning-arrester grounds is believed to have a material effect upon the degree of protection rendered, the data have been analyzed to determine such effects in tables XVI and XVII. In the analyses it will be noted while no consistent trend is evident that in general the trend of primary fuses blown and transformer-winding failures are upward as the ground resistance increases. When it is considered that the data are analyzed by the average ground resistance of each company reporting and that this average ground resistance is estimated, it is evident that these two tables cannot be considered entirely conclusive. However, it is believed that they are indicative of general trends.

Table XVI in most cases, except for the three-point connection, has sufficient number of installations in each range of ground resistances. However, this table includes all types of territory. When the data for rural installations only is segregated as in table XVII, too few installations exist in many ranges of ground resistances to give usable averages. In table XVII it should be noted that the rate of primary fuses blown and transformer winding failures for ground resistances up to 30 ohms are slightly higher for interconnection than for the standard connection. This may be due in part to the inclusion of gapped interconnection in the classification

Table XIII. Combined Operating Data on Various Methods of Protecting Distribution Transformers From Lightning for 1935 and 1936

All Types of Territory

Type of Protection	Average Number Installations	Average Ground Resistance	Failures per 100 Installations: Primary Fuses Blown: Total	Lightning Arrester on Line Side of Fuse	Lightning Arrester on Transformer Side of Fuse	Transformer Windings Damaged: Total	Primary Only	Secondary Only	Primary and Secondary	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	153,698	59.0	5.08	4.55	6.29	0.655	0.214	0.081	0.317	0.878	1.04	0.100
Solid interconnection	123,102	10.7	1.36	1.01	2.12	0.333	0.068	0.030	0.130	0.455	1.37	0.092
Solid interconnection with tie to case	2,715	27.9	1.80	1.40	N.D.	0.276	0.096	0.096	0.145	0.049	0	0
Gapped interconnection	14,627	56.1	9.20	5.23	12.40	0.634	0.254	0.053	0.561	0.875	2.12	0.156
Gapped interconnection with tie to case	1,125	36.9	24.90	13.99	16.67	1.42	1.72	0.172	0.432	2.08	0.435	0
Common primary and secondary neutral	40,734	10.1	1.74	1.10	5.15	0.413	0.063	0.007	0.053	0.300	0.343	0.085
Surge proof transformer	3,850	48.1	5.81			0.442	0.048	0.048	0.178	0.840*	0.046	0.115
Three-point protection	1,016	44.0	5.05	17.45	N.D.	0.595	0.347	0.099	0.149	3.61	0.115	0.405
CSP transformer	3,215	64.2	0.172			0.234	0.018	0.018	0.106	0.127*	0.074	0.112

* Deion gap failures per 100 installations.

Table XIV. Combined Operating Data on Various Methods of Protecting Distribution Transformers From Lightning for 1935 and 1936

Rural Installations

Type of Protection	Average Number Installations	Average Ground Resistance (Ohms)	Failures per 100 Installations: Primary Fuses Blown: Total	Lightning Arrester on Line Side of Fuse	Lightning Arrester on Transformer Side of Fuse	Transformer Windings Damaged: Total	Primary Only	Secondary Only	Primary and Secondary	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	17,756	106	12.17	11.45	N.D.	0.691	0.259	0.175	0.278	2.90	2.25	0.301
Solid interconnection with and without tie to case	4,903	18.2	5.26	4.88	5.39	1.55	0.066	0.022	0.088	0.932	0.572	0.215
Gapped interconnection with and without tie to case	13,408	46.3	10.63	5.83	13.70	0.714	0.691	0.067	0.780	1.07	2.06	0.075
Common primary and secondary neutral	3,383	13.7	6.28	1.32	8.98	0.358	0.129	0.032	0.193	0.392	0.166	0
Surge-proof transformer	832	52.2	8.53			0.361	0.131	0	0.197	0.945*	0	0.075
Three-point protection	219	47.5	9.81	18.60	N.D.	0.456	0.228	0	0.228	9.75	0	0.772
CSP transformer	834	89.5	0.376			0	0	0	0	0.198*	0.123	0.135

* Deion gap failures per 100 installations.

Table XV. Combined Operating Data Upon Various Methods of Protecting Distribution Transformers From Lightning for 1935 and 1936

Urban and Suburban Installations

Type of Protection	Average Number Installations	Average Ground Resistance (Ohms)	Failures per 100 Installations: Primary Fuses Blown: Total	Lightning Arrester on Line Side of Fuse	Lightning Arrester on Transformer Side of Fuse	Transformer Windings Damaged: Total	Primary Only	Secondary Only	Primary and Secondary	Lightning Arrester Failures	Customers' Meters Burned Out	Customers' Wiring, Etc., Damaged
Standard connection	105,029	76.6	3.34	3.11	5.80	0.687	0.228	0.056	0.290	0.465	0.731	0.063
Solid interconnection with and without tie to case	74,637	10.2	1.05	0.552	1.90	0.185	0.031	0.028	0.073	0.174	1.91	0.104
Gapped interconnection with and without tie to case	1,876	61.3	6.75	1.87	3.89	0.464	0.121	0.030	0.303	0.460	1.16	1.19
Common primary and secondary neutral	26,670	8.3	0.749	0.438	3.96	0.180	0.053	0.003	0.030	0.337	0.378	0.100
Surge-proof transformers	325	33.4	9.47			0.462	0.154	0	0.308	0.156*	0.167	0.168
Three-point protection	429	8.0	3.57	N.D.	N.D.	0.350	0.117	0.117	0.117	1.71	0.122	0.792
CSP transformers	396	49.5	0.214			0.253	0	0	0.253	0.127	0	0.370

* Deion gap failures per 100 installations.

Table XVI. Effect of Ground Resistance Upon Operating Data for Various Methods of Protecting Distribution Transformers From Lightning—1934, 1935, and 1936 Lightning Seasons

All Types of Territory

Type of Protection	Range of Average Ground Resistance (Ohms)	Average Number of Installations	Number of Companies 1934	1935	1936	Failures per 100 Installations: Primary Fuses Blown	Transformer Windings Damaged	Lightning Arrester Failures	Customers' Meters Damaged	Customers' Wiring, Etc., Damaged
Standard connection (figure 1)	1– 10	17,166	3	4	4	3.50	0.425	0.930	0.653	0.625
	11– 20	25,542	5	8	4	3.82	0.743	0.432	2.00	0.084
	21– 30	7,376	3	2	5	3.34	0.344	0.262	0.316	0.168
	31– 40	9,051	2	3	2	2.92	0.558	0.188	0.495	0.069
	45– 75	5,477	1	5	4	5.91	1.31	0.711	1.92	0.129
	80–125	28,181	4	0	0	10.4	0.92	2.67	0.996	0.883
	200–250	9,772	2	2	1	20.5	1.26	3.84	1.47	0.101
Solid interconnection (figures 2 and 3) and common primary and secondary neutral (figure 6)	0– 1	40,761	7	6	10	0.545	0.112	0.256	1.43	0.050
	2– 5	13,291	5	8	6	1.35	0.216	0.199	0.272	0.100
	6– 10	29,585	4	3	6	1.91	0.260	1.49	0.211	0.152
	11– 20	22,375	0	6	4	6.65	0.410	0.480	0.236	0.043
	21– 30	4,077	5	3	4	1.84	0.163	0.143	0.019	0.039
	50–133	6,858	2	2	0	18.52	0.74	0.484	0	0
Gapped interconnection (figures 4 and 5)	0– 10	921	2	2	3	3.40	0.217	0.094	0	0.080
	11– 20	5,439	0	4	2	13.90	0.792	1.35	0.81	0.101
	21– 30	1,724	1	2	8	10.70	0.600	1.28	0.726	0
	31– 50	542	1	1	1	11.50	1.23	1.54	1.29	0.064
	51–100	1,030	0	2	2	5.96	2.09	1.36	3.74	0
	101–250	516	1	1	1	2.91	0.324	0.453	0	.259
Surge-proof transformers (figures 7 and 9)	1– 25	761	7	8	6	1.75	0.657	0.228*	0	0
	26–100	857	5	3	6	6.45	0.272	0.823*	0.185	0.063
	101–400	378	2	4	1	7.40	0.176	2.03*	0	0.176
Three-point protection (figure 8)	1– 10	150	2	1	2	5.70	0.89	1.60	0.320	0.970
	11– 20	121	1	1	1	1.54	0.55	0	0	0.276
	21– 30	35	1	0	1	4.35	0	4.35	0	0
	70– 80	86	1	1	0	13.95	0	16.87	N.D.	0.91
	175	723	0	1	0	3.60	0.969	1.24	0	0

* Deion gaps damaged per 100 installations.

Table XVII. Effect of Ground Resistance Upon Operating Data for Various Methods of Protecting Distribution Transformers From Lightning—1934, 1935, and 1936 Lightning Seasons

Rural Installations

Type of Protection	Range of Average Ground Resistance (Ohms)	Average Number of Installations	Number of Companies 1934	1935	1936	Failures per 100 Installations: Primary Fuses Blown	Transformer Windings Damaged	Lightning Arrester Failures	Customers' Meters	Customers' Wiring, Etc., Damaged
Standard connection (figure 1)	1– 30	4,976	2	2	6	3.09	0.173	0.45	0.52	0.01
	40– 70	712	1	1	3	27.9	2.30	2.94	10.43	0.423
	71–100	164	2	0	1	11.30	2.75	N.D.	1.81	N.D.
	200–250	4,686	0	2	1	11.70	0.45	4.07	2.70	0.160
All types of interconnection (figures 2, 3, 4, 5, and 6)	0– 10	7,533	0	0	13	4.46	0.44	0.73	0.18	0.19
	11– 20	7,207	0	6	3	12.10	0.62	1.10	0.64	0.08
	21– 30	2,130	3	3	7	8.49	0.58	1.12	0.34	.09
	31– 50	1,588	1	2	4	20.9	2.98	0.73	0.80	0
	51– 60	283	0	1	0	3.53	0.71	1.77	0	0
	75– 90	563	0	2	2	11.20	3.02	1.87	5.50	0
	101–250	195	1	0	1	4.89	0	0.34	N.D.	0
Surge-proof and *CSP* transformers (figures 7 and 9)	1– 25	131	4	6	1	1.35	0	0.51	0	0
	26–100	696	3	2	6	5.79	0.24	0.98	0.13	0
	101–400	418	2	5	0	9.10	0.372	2.62	0	0.12
Three-point protection (figure 8)	1– 10	20	1	0	0	5.00	5.00	0	0	0
	11– 20	95	1	0	1	1.05	1.05	0	0	0.53
	21– 30	35	1	0	1	8.57	0	8.57	0	0
	70– 80	94	1	1	1	17.00	0	12.10	N.D.	N.D.

of interconnection. The data in table XVI show the reverse trend when the standard connection and solid interconnection only are compared. This leads to the conclusion that a large part of the improvement noted by the use of solid interconnection is the result of the lower values of ground resistance that almost invariably exists when the latter is used.

Effect of Operating Voltage

An analysis of the data by operating voltage has been made in tables XVIII, XIX, and XX. In drawing this comparison allowance has been made for type of territory, ground resistance, and location of primary fuse. Due to lack of data no comparison could be drawn for urban and

Table XVIII. Effect of Operating Voltage and Average Ground Resistance on Operating Data for Various Methods of Lightning Protection—1935 and 1936 Lightning Seasons

All Types of Territory

Type of Protection	Range of Average Ground Resistance (Ohms)	Average Number of Installations			Failures per 100 Installations																	
					Primary Fuses Blown																	
					Lightning Arrester on Line Side of Fuse			Lightning Arrester on Transformer Side of Fuse			Transformer Windings			Lightning Arresters			Customers' Meters Burned Out			Customers' Wiring, Etc., Damaged		
		1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv	1–5 Kv	6–10 Kv	11–15 Kv
Standard connection (figure 1)	1– 10	18,392	523*	101*	2.58	20.6	28.8	N.D.	N.D.	N.D.	0.283	0.382	1.98	1.13	N.D.	N.D.	0.352	N.D.	N.D.	0.625	N.D.	N.D.
	11– 25	22,408	4,026	945	2.00	10.2	7.45	N.D.	N.D.	N.D.	0.577	0.475	0.423	0.485	2.99	1.89	1.70	N.D.	0	0.162	N.D.	N.D.
	26– 50	7,875			2.46			N.D.			0.665			0.480			0.064			0.021		
	51–100	10,695			3.54			N.D.			0.705			0.206			0.424			N.D.		
	200–250	7,945			6.86			2.52			0.315			2.28			1.47			0.082		
Solid interconnection with and without tie to case (figures 2 and 3)	0– 1	39,754			0.725			1.17			0.114			0.167			1.67			0.036		
	1– 5	9,541			0.926			0.875			0.152			0.352			0.067			0.187		
	6– 10	23,529			1.39			1.20			0.047			0.089			0.25			0.122		
	11– 20	27,398	930	1,049	14.1	N.D.	0	8.25	N.D.	6.30	0.545	0.645	0.191	1.50	N.D.	1.07	6.86	0	0.048	0.336	0	0
	21– 30	501			3.51			1.11			0.40			0.85			N.D.			0.200		
Gapped interconnection with and without tie to case (figures 4 and 5)	0– 10	1,515	None	11*	3.96		15.40	2.18		11.1	0.278		4.55	0.132		0	N.D.		0	0.080		0
	11– 20	None	None	139			10.00			58.5			0			0			0			0
	21– 30	5,168	None	58*	1.92		10.00	1.40		30.3	0.773		3.03	0.958		N.D.	0.135		N.D.	0.106		N.D.
	50– 75	702	83*	266	6.19	N.D.	1.43	N.D.	1.67	N.D.	2.78	2.41	3.76	1.14	0	3.76	1.07	0	0	N.D.	0	0
	75–100	573	None	None	N.D.			N.D.			0.349			2.10			2.62			0		
	250	725	None	None	N.D.			2.48			0.345			0.483			N.D.			0.276		
Common primary and secondary neutral (figure 6)	0– 5	14,195	None	None	0.328			N.D.			0.127			0.440			0.517			0.138		
	6– 10	504*	None	None	0			N.D.			0			0.20			N.D.			N.D.		
	11– 20	None	None	2,111			N.D.			9.13			0.284			0.412			0.412		0
	21	4,600*	None	None	0.413			N.D.			0.065			0.043			0			0		
Westinghouse surge-proof transformers (figure 7)	0– 25	187	38	None	0	15.5					0.266	0		0	0		0	0		0	0	
	26–100	38	24	None	10.52	20.8					2.63	0		0	0		0	0		0	0	
	100–150	927	None	None	20.5						0.54			2.48			N.D.			0.108		
Westinghouse *CSP* transformers (figure 9)	0– 10	106	None	7*	0		14.28				0.47		0	0.5		0	0		N.D.	0		N.D.
	11– 25	19	207	None	N.D.						0	0		5.26	0	0	0	0	0	0	0	
	26– 50	None	43*	45*		0	2.22				0	2.22		0	2.22		0	0	0		N.D.	0
	51– 75	155	None	None	0						0			0			0			0		
	250	22	None	None	0						0			0			0			0		

* Based on report of only one company for either one or two years.

Insufficient data for tabulation on three-point protection—figure 8.

suburban installations for voltages above 5 kv (see table XX). It is thought that the data indicates that in spite of the paucity of data the trouble rates are higher for the higher distribution voltages.

LOCATION OF TRANSFORMER WINDING FAILURES

Where possible data were obtained relative to the location of transformer-winding failures, i.e., whether the primary only, the secondary only, or both the primary and secondary were involved in the failure. While with some types of protection a sufficient number of failures to indicate trends have not been reported, a sufficient number have been reported for several types of protection. These data have been summarized in table XXI. Except for the gapped interconnection, the *SP* and *CSP* transformers in which cases relatively few failures were reported, the various types of protection show consistent trends.

SECONDARY PROTECTION

Since the average data in table XXI show that in 64.8 per cent of the transformer winding failures the secondaries are involved, the question arises as to whether or not this high percentage may be due to the lightning surges entered from the secondary. A secondary-winding failure does not necessarily mean a secondary entrance of the surge as a surge entering through the primary in its attempt to reach the

Table XIX. Effect of Ground Resistance Upon Operating Data for Various Methods of Protecting Distribution Transformers from Lightning—1935 and 1936 Lightning Seasons

Rural Installations

Type of Protection	Range of Average Ground Resistance (Ohms)	Average Number of Installations			Failures per 100 Installations																	
					Primary Fuses Blown						Transformer Windings Damaged			Lightning Arrester Failures			Customers' Meters Burned Out			Customers' Wiring, Etc., Damaged		
					Lightning Arrester on Line Side of Fuse			Lightning Arrester on Transformer Side of Fuse														
		1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky	1-5 Ky	6-10 Ky	11-15 Ky
Standard connection (figure 1)	7- 15	None	342	188		N.D.	13.89		N.D.	N.D.		.542	0.354		2.99	N.D.		N.D.	0			N.D.	0
	21- 30	2,082	None	871*	5.38		N.D.	N.D.		N.D.	0.387		0.270	0.720		1.89	N.D.		0			N.D.
	31- 40	None	None	350*		18.00			N.D.			2.86		3.43			N.D.					
	66- 75	1,901	None	None	15.53			N.D.			2.10			1.84			1.58			0		
	200-250	3,721	None	None	11.35			5.40			0.43			4.07			2.70			0.134		
All types of interconnection	0- 10	2,418	None	2,068	3.04		N.D.	2.45		0.24	0.394			0.195		0.680	1.06		0.400	0.048		0.329	0
	11- 20	5,319	None	3,777	4.61		10.0	14.4		10.30	0.743			0.265		0.969	0.715		0.142	0.476		0.111	0
	21- 30	786	None	116	3.16		10.0	3.00		30.30	3.82			3.03		0.792	0		0	0		0.127	0
	50- 60	200*	1,214	563	N.D.		N.D.	N.D.	1.6	N.D.	0	2.81	0.59	1.67	0	3.76	0	0	0	0	0	0
	75- 90	563	None	None	12.31			N.D.			3.02			1.80			5.50			0		
	250	291*	None	None	N.D.			3.44			0			0.344			N.D.			0		

Insufficient data for tabulation on *SP* and *CSP* transformers and three-point protection.

* Based upon single company for either one or two years.

ground may flash over a secondary bushing and raise the potential of the secondary winding sufficiently to cause it to fail. On the other hand the rate of meter failures per hundred transformers shown in tables X to XV indicate the possibility of surges on the secondary.

Of the companies reporting six report the use of secondary protection. In most of these cases secondary protection is used in a few installations apparently as an experiment. However, one company makes it a practice to install secondary arresters on polyphase meters and another company installs secondary arresters at customers where electric ranges are installed.

Effect of Fusing Schedule

Since the primary fusing schedule used by any company cannot be expressed in a single numerical statement, any comparison must be only approximate. In making the comparison in table XXII an attempt has been made to reduce all the fusing schedules to a percentage basis. In spite of the fact that no definite trend is established it is believed that irrespective of the type of protection used the rate of primary fuses blown should decrease with the use of higher rated fuses. This has been borne out by studies made by several individual companies.

Effect of Location of Primary Fuse

As a result of the question raised regarding the effect of the surge current causing the primary fuse to blow, the data have been analyzed in tables XIII to XV showing the rates of fuse blowing when the primary fuse is installed on the line side of the arrester separate from those when the fuse is installed on the transformer side of the arrester. From a study of these tables it is apparent that with all types of protection the rates of primary fuses blown are higher when the arrester is on the transformer side of the fuse and the surge current passes entirely through the fuse.

Effect of One or Two Fuses per Transformer

In three-phase four-wire systems it is customary to connect single-phase transformers between phase and neutral using a single fuse; whereas in three-phase three-wire systems single-phase transformers must be connected between phases necessitating two fuses per transformer. In table XXIII a comparison is drawn to determine whether or not there is any difference in the number of fuses blown per hundred transformers when one or two fuses per transformer are used. The data show that the rates of primary fuses blown are practically the same in both cases.

Grounding of Transformer Tanks

Since theory, laboratory tests, and certain field data indicate that if the transformer tank is left free to assume any potential a greater strain may be imposed upon the insulation by lightning surges than if the tank were held at ground potential, a growing tendency to ground the tanks of distribution transformers is noted. Fourteen of the companies reporting state that they ground the transformer tanks on some 40,437 transformers. Seven

Table XX. Effect of Ground Resistance Upon Operating Data* for Various Methods of Protecting Distribution Transformers From Lightning—1935 and 1936 Lightning Seasons

Urban and Suburban Installations

Type of Protection	Range of Average Ground Resistance (Ohms)	Average Number of Installations	Failures per 100 Installations: Primary Fuses Blown — Lightning Arrester on Line Side	Primary Fuses Blown — Lightning Arrester on Transformer Side	Transformer Windings Damaged	Lightning Arrester	Customers' Meters	Customers' Wiring, Etc.
Standard connection (figure 1)	1– 10	19,657	1.70	N.D.	0.333	1.04	N.D.	N.D.
	11– 15	9,716	2.18	N.D.	0.710	0.653	1.89	0.085
	16– 20	11,605	3.51	N.D.	0.860	N.D.	N.D.	N.D.
	21– 30	4,510	1.10	N.D.	0.266	0.213	0.482	N.D.
	31– 50	5,867	1.66	N.D.	0.698	0.595	0.038	0.038
	70–100	10,501	3.32	N.D.	0.680	0.176	0.317	N.D.
	200	7,336	2.34	N.D.	0.177	0.819	N.D.	0.028
	250	567	N.D.	1.41	0.176	0	1.06	0
All types of interconnection (figures 2, 3, 4, 5, and 6)	0– 1	47,291	0.638	7.90	0.115	0.184	0.570	0.021
	1– 3	11,542	0.378	0.751	0.100	0.332	0.145	0.186
	4– 10	8,282	1.08	1.20	0.179	0.376	1.32	0.715
	11– 30	12,950	0.580	1.05	0.555	0.049	0	0
	50	6,364	N.D.	N.D.	0.188	0.487	N.D.	N.D.

* This data for 0–5 kv only; insufficient data for tabulation for 6–15 kv.
Insufficient data for tabulation on three-point protection, surge-proof and *CSP* transformers.

companies ground the tanks on 18,478 transformers protected with the standard connection. Six companies do the same on 2,684 transformers using solid interconnection. Three companies ground the tanks on 1,340 transformers using gapped interconnection. Nine companies using the common primary and secondary neutral ground the tanks on 17,935 transformers.

Table XXI. Location of Transformer Winding Failures Expressed as Per Cent of Total Failures—1935 and 1936 Lightning Seasons Combined

All Types of Territory

Type of Protection	Number of Segregated Transformer Failures	Per Cent Primary Only	Per Cent Secondary Only	Per Cent Primary and Secondary
Standard	685	35.8	11.1	53.1
Solid interconnection	307	29.6	13.4	57.0
Solid interconnection with tie to case	7	28.6	28.6	42.8
Gapped interconnection	65	29.2	6.2	64.6
Gapped interconnection with tie to case	27	74.1	7.4	18.5
Common primary and secondary neutral	53	51.0	5.6	43.4
Surge proof	17	17.6	17.6	64.8
Three-point protection	12	58.3	16.7	25.0
CSP	8	12.5	12.5	75.0
Total	1,181	35.2	11.3	53.5

Table XXII. Effect of Fusing Schedule on Number of Primary Fuses Blown—1935 and 1936 Data Combined

Fuses on Transformer Side of Lightning Arrester

Schedule Range (Per Cent)	Standard Connection: Number Installations Involved	Standard Connection: Per Cent Primary Fuses Blown	Interconnection (All Types): Number Installations Involved	Interconnection (All Types): Per Cent Primary Fuses Blown
150–200	26,134	3.78	Insufficient data	
201–250	20,324	4.60	57,221	1.43
251–300	31,835	4.30	3,173	2.27
301–400	Insufficient data		36,300	1.39
401–500	1,517	3.89	Insufficient data	

Limitations Placed on Ground Resistance

Since the data indicate that the value of resistance of the arrester ground is a factor of major importance in rendering effective lightning protection, the practice of the various companies in reducing or placing limitations on ground resistance has been analyzed in table XXIV. Of the 44 groups of installations of the standard connection only 15 make any specific attempt to lower or to limit the ground resistance. On the other hand only seven groups of installations of solid interconnection have no limitation on the ground resistance of which five have grounds salted. Of the 33 groups of installations of solid interconnection 13 have definite limitations

Table XXIII. Difference Upon Rate of Primary Fuses Blown Due to One or Two Primary Fuses per Transformer—1935 and 1936 Data Combined

Type of Protection	One Fuse per Transformer Installation: Average Number Installations	One Fuse per Transformer Installation: Fuses Blown per 100 Transformers	Two Fuses per Transformer Installation: Installations	Two Fuses per Transformer Installation: Fuses Blown per 100 Transformers
Standard	43,080	5.60	27,574	5.22
Solid interconnection	55,200	0.945	34,630	1.84
Solid interconnection with tie to case	103	2.91	1,808	1.66
Gapped interconnection	7,516	10.4	3,950	7.80
Gapped interconnection with tie to case	0	N.D.	483	28.60*
Type *SP* transformer	1,302	6.72	504	4.66
Three-point protection	293	7.85	617	3.72
Type *CSP* transformer	640	0.08	261	0.19
Total—all types	108,134	3.54	69,827	3.74

* Based on one company which had much damage done by a severe storm during 1936.

Table XXIV. Ground Resistance Limitations Placed Upon Various Schemes of Lightning Protection—1935 and 1936 Data

	Standard Connection	Solid Interconnection	Solid Interconnection Tie to Case	Gapped Interconnection	Gapped Interconnection Tie to Case	Common Primary and Secondary Neutral	Surge-Proof Transformers	Three-Point Protection	CSP Transformers
Installation Groups Reported Upon	44	33	6	24	4	20	21	7	25
Number reducing ground resistance to specified value:	15	13	1	7	2	6	5	2	6
200 ohm					1				
100 ohm	1					1			
50		2	1	2					
30	2	1		1				1	1
25	6	3		2		1	3	1	2
20					1				
15	4	3		1		1	2		2
10		3		1					
5						2			1
Less than 5	2	1				1			
By salting only	1			1					1
Water pipe grounds	1	3							
Driven grounds	4	3		1		3	3	1	2
Salting and water pipes		2							
Salting and driven grounds	5		1	2	2	1	1	1	1
Water pipe and driven grounds		1				1			
No method	4	4		3		1	1		2
Number specifying water pipes only:	1	5	2	2	1	1			
1	1	2							
2		1	1	1		1			
3		2		1	1				
4									
5									
Number specifying driven grounds only:		5	1	8			3		1
1		1	1	6			1		
2		1		2			1		1
3		3					1		
Number specifying either water pipe or driven grounds:									
One water pipe, two driven		3							
Two water pipe, one driven		2							
Two water pipe, two driven		1							
Number salting grounds without limitation as to resistance		3		1	1		1		3
Number salting grounds and driving rods without limitation as to resistance	1	2		2		1	1	1	1
No limitation	27	2	2	4		12	11	4	14
Number placing limitation because of:									
Experience		8	1	4	1				
National Electrical Code		3		5					
Both		1		3					

N.B. Installation group does not necessarily mean company. Some companies impose limitations upon certain territories or certain voltages.

of the maximum value of ground resistance, eight require water pipe grounds, and four require more than one driven ground.

Discussion

Herman Halperin (Consolidated Edison Company, Chicago, Ill.): While analysis of extensive data involving numerous variables generally proves difficult, Smith has done a commendable job. The large number of tables, which at first seems confusing, presents the data in such a way as to make further analysis readily possible.

From the standpoint of protection to equipment, it is of interest to examine the combined rates of transformer winding failures and fuse blowings. The combined figures for 1935 and 1936, expressed as the ratio of transformer and fuse troubles to similar troubles with the solid interconnection, were: common neutral, 1.3; standard connection, 3.4; gapped interconnection, 5.8. For the remaining protective schemes, including the self-protecting types of transformers, the numbers of installations involved were statistically insufficient, that is, only a few per cent of the number with solid interconnection, and definite conclusions for these types appear unwarranted as yet.

In view of the fairly extensive application of the gapped interconnection, it must be disturbing to a number of companies to learn of the generally poor performance of this protective scheme. With this connection, the surge voltage impressed on the transformer is that permitted by the phase arrester plus the drop in connecting leads and plus the breakdown of the spark gap. This latter value may be about the same as the voltage across the lightning arrester. Two alternative improvements may be suggested for such installations: (*a*) reduction in breakdown voltage of the interconnection gap, by the use of lower rated or special gaps; or (*b*) a change to the solid interconnection. The objection to this latter connection was based mainly upon fear for the customers' safety, but, according to our Chicago studies ("Lightning Investigations on a Distribution System," Halperin and Grosser, ELECTRICAL ENGINEERING, January 1936, pages 63–70) and the data in this paper, this objection to solid interconnection is of no consequence and should gradually disappear.

Conclusion 3 of the paper, indicating that the rate of arrester failures is lower with solid interconnection than with the standard connection, is based on a general averaging of the data from all com-

panies. This conclusion does not seem to be entirely justified by the data, when the operating records of individual companies are considered. Of 12 companies, which report on a sufficiently large number of installations of both types to be suitable for comparison, seven, including Chicago, showed higher rates of arrester failure with the solid interconnection than with the standard connection. Theoretically, some increase in failure rate should be expected with solid interconnection, because of the greater duty on the arrester in discharging surge current to a low resistance ground. The best way to determine the effect of one variable is to have just one variable in the study, and that was the case in Chicago when we had both solid interconnection and standard connection of arresters for a few years over various parts of the city and found that arrester failures were relatively high with the solid interconnection.

The installation of the solid interconnection in Chicago was very much cheaper than trying to improve the ground resistance with the standard connection. The solid interconnection was obtained simply by the installation of a short piece of Number 6 wire between the ground side of the arresters and the secondary neutral. The effect of the solid interconnection in Chicago was to reduce the total rate of transformer failures and fuse blowings by over 50 per cent as compared to the rate that obtained with the standard connection of arrester.

Regarding conclusion 8, while it is recognized that the majority of the reported installations of secondary arresters were of an experimental nature, it would be of interest to learn something of the reasons for providing these protective measures.

The compilation of a large amount of data such as this may make it possible to analyze the effect of thunderstorm frequency on lightning troubles. It is suggested that the next questionnaire circulated should be modified to determine, for the four years beginning with 1934, the number of thunderstorms per year, both from weather bureau and company records, and an attempt made to correlate these data with lightning trouble rates.

W. A. McMorris (General Electric Company, Pittsfield, Mass.): Mr. Smith and those who have co-operated with him in the accumulation and analysis of operating data on distribution circuits, are to be congratulated on what they have accomplished. Differences in the types and ages of equipment in use, and in the conditions under which it must operate, require a study of broad scope in order that definite trends in performance may be established.

The data obtained have made it possible to draw a number of conclusions with regard to best operating practices. A few inconsistencies still remain, but it is to be expected that these will decrease in number as the investigation is continued.

On page 5 of the preprint it is stated that "the fear that has been expressed that with solid interconnection a heavier duty may be placed on the arrester causing more failures is without foundation." This conclusion is well supported, without contradictions, by data in tables X to XV, inclusive. Table X which summarizes the results, shows an arrester failure rate of 1.17 per hundred for 159,138 installations with standard connection, and only 0.551 per hundred for 146,738 installations with solid interconnection. Rather than increasing the arrester failure rate, solid interconnection has reduced it to 47 per cent of the value for standard connection, and to 57.5 per cent of the value for gapped interconnection, the nearest competitor in this table.

Information given in recent AIEE papers by Mr. Flanigen ("Lightning Protection of Distribution Transformers," AIEE TRANSACTIONS, volume 54, pages 1400–05, December 1935) and by Messrs. Halperin and Grosser ("Lightning Investigations on a Distribution System," AIEE TRANSACTIONS, volume 55, pages 63–70, January 1936) suggests that many arrester failures result from other causes than high-current lightning discharges. This was borne out in the investigation reported in the paper by Mr. McEachron and myself, presented at this convention, in which measurements were made of the discharge currents associated with arrester failures. Figure 11 of that paper shows a very small percentage of arrester failures to be due to high discharge currents.

The obvious conclusion is that solid interconnection probably does result in some increase in the magnitude of currents passed by arresters, but that high current discharges are not a major cause of arrester failure, so the predicted increase in arrester failure rate does not occur. Interconnection may result in an increase in arrester discharge currents by lowering ground resistances, but this tends to localize the disturbance so that fewer arresters operate.

This possibly helps to explain the lower arrester failure rate with solid interconnection. Failures from power current resulting from sixty-cycle overvoltage, gap corrosion, or similar causes, would decrease as the number of arrester operations is decreased by localizing the disturbances, more or less independently of any change in the magnitude of lightning discharge currents.

In general, the performance of the various gapped interconnections, including three-point protection and surgeproof transformers, has been considerably less satisfactory, even though the surgeproof transformers and their deion gaps were all new equipment. The protective scheme of the surgeproof transformer is essentially a gapped interconnection, and the over-all service performance from table X does not appear to be greatly out of line with that of other gapped interconnections.

Since the paper reports field data for 1934, 1935, and 1936, the surgeproof transformers referred to are presumably of the type with the deion gap inside the transformer tank. With such a protective device inherently a part of the transformer, either winding failure or gap failure would probably require transformer removal and maintenance.

Table X, summarizing all data, shows 1.21 gap failures and 0.43 winding failures per hundred installations of surgeproof transformers, compared to values of 0.551 and 0.350, respectively, for conventional transformers protected by valve-type arresters with solid interconnection. In some cases, both gap and winding failures may have occurred on the same transformers, so the number of surgeproof transformers requiring maintenance, per hundred installed, would be between 1.21 and 1.64. For solid interconnection with valve-type arresters mounted outside the transformer tank, arrester failure alone does not make transformer replacement or maintenance necessary, and only 0.350 transformers per hundred installed would have to go to the shop. Thus for the surgeproof transformers, all of which were relatively new, maintenance was required from 3.5 to 4.7 times as often as for the older standard transformers with solidly interconnected arresters. Both table XI showing data from rural circuits, and table XII showing data on urban and suburban circuits, but which are based on many fewer installations than table X, indicate that more transformer maintenance is required for surgeproof transformers than for standard transformers with solid interconnection.

Such an analysis based on the data reported in the paper, shows that distinct disadvantages result from combining the protective device with the transformer in such a way that the failure of the protective device is likely to interrupt service of the transformer or require its removal for maintenance. Similarly it is shown that the full benefits of interconnection are not realized by any of the schemes in which the interconnection is made through a gap.

F. E. Andrews and **R. O. Askey** (Public Service Company of Northern Illinois, Chicago, Ill.): As a result of a brief study of the data in this paper made within the short time during which a printed copy has been available, it appears that there are several factors which may influence the various failure rates and which may be of greater importance in the results shown by the different types of protection than the inherent differences in the protective scheme.

It is noted in table X summarizing results of all types of territory that the rate of primary fuses blown is in general higher with the gapped interconnection than either the solid interconnection or standard connection. It is also noted by reference to table XI that 82 per cent of the total number of gapped interconnection installations are classified as rural and that for the rural installations there is less difference in performance of the gapped installation in comparison with the others. As noted in the text of the paper, the failure rate for the rural installations for all types of protection is apparently considerably higher than for urban, which suggests that

differences in exposure, arrester density, etc., which are inherent in the nature of the territory probably have a considerable influence.

We have noted in studies of our operating data with respect to the interconnection, much the same relationship with respect to the gapped interconnection as is indicated by the data in the paper. We have also noted in attempting to explain the apparent failure of the gapped interconnection to perform as satisfactorily as the solid interconnection that the gapped interconnection in general has been used in a much larger proportion of situations where grounding conditions are less satisfactory and where specific trouble due to fuse blowing has been previously experienced. This trouble due to the larger amount of fuse blowing has been found in many instances to have been due to inadequate lead and bushing insulation such that even with the interconnection satisfactory co-ordination with the lightning arrester could not be obtained. Under this condition it has been apparent that material improvement by the use of the interconnection could not be expected.

It would accordingly seem that if data on the various types of protection are to be compared purely on the merits of the various protective schemes it is necessary that the transformers involved also be classified in such a manner as to factor out those of known susceptibility to trouble of this nature. The principal items affecting this susceptibility are probably transformer size, age, and manner in which maintenance and repair work have been done. In line with this idea it would seem advisable to set up a separate grouping to include only transformers built according to present day standards which in general would probably include those bought since about 1934.

In furtherance of this idea we have made a partial study of performance of these newer transformers and while at the present time we cannot give specific data on them with reference to the different types of protection, it is obvious that rates of failure substantially different from those applying to the older transformers on the system will be found. One apparently significant point has been developed thus far from this investigation. It was believed that with new transformers of adequate design with respect to leads and bushings, it should be relatively easy to determine the explanation for each case of fuse blowing. We accordingly investigated the record of 41 cases of fuse blowing in a group of 672 modern transformers in the size range from one and one-half to seven and one-half kva, inclusive. The results of this investigation are shown as follows:

Number of transformers in group	672
Total number of fuse operations	41
Number of installations at which fuses were blown	30
Number of installations inspected in detail. (The arresters were connected to the line side of the fuse on all of these installations.)	13
Installations showing evidence of lead or bushing flashover	5
Installations at which no evidence was found to explain the fuse operations	8

From this data it is evident that there were a few cases in which transformer fuses were blown due to bushing flashovers in spite of the lightning arrester protection. There were, however, eight cases in which no ordinary explanation of the fuse blowing was evident. The transformers at these eight locations at which fuse blowing occurred were given the standard AIEE high-potential tests to determine if fuse blowing might have been caused by a coil puncture which was sealed off, perhaps by the transformer oil. All of these transformers stood the high-potential test successfully, indicating that the fuse failure occurred without passage of fault currents through the fuse.

An investigation, now in progress, of the performance of a similar group of modern transformers has disclosed that a number of instances of fuse blowing without leaving visible evidence of the path of the current responsible have occurred. In general these have been at rural installations using three- and five-ampere fuses and with the lightning arresters connected to the line side of the cutout. For the most part, these have been confined to gapped interconnected installations in rural territory.

These data point to the likelihood of the fuse blowing being due to some other type of current through the primary fuse not heretofore recognized in connection with distribution transformers such as perhaps transients due to capacity coupling from primary winding to secondary or to core and tank. There is also the possibility of high current in the fuse due to resonance between the inductance of the transformer and the capacity of the interconnection gap. It is believed that with modern transformers, at least in the smaller sizes, a relatively large proportion of fuse blowings is due to the effect described above and that it is important to direct any future investigation toward an explanation of this effect.

W. G. Roman (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): This report has tabulated a large mass of data on distribution transformer lightning-protection practice. Since these data were taken from a large number of operating companys they represent an interesting cross section or average practice.

An examination of table X shows the solid interconnection gives the best all around lightning protection although the meter burnouts are relatively high. These data are somewhat conflicting since the damage to customer's wiring is the lowest for the solid interconnection. The reasons for the low arrester failure rate for the solid interconnection are not obvious. Because of the lower effective ground resistance of the interconnection the surge currents discharged by the arrester should be higher and should result in a higher arrester failure rate. The lower rate shown in the table may be because installations having the solid interconnection also on an average have more modern arresters.

Table XVI shows that for the standard connection the low ground resistance is definitely desirable in reducing trouble. For the various forms of interconnection this is not apparent which checks with what is to be expected since in the interconnection schemes the ground drop is not added to the voltage appearing across the protective device. The reason for the high meter-failure rate for the solid interconnection for ground resistances of zero to one ohm is not apparent unless these low ground resistances are usually obtained by tying the secondary neutral to the water system on the customer's premises. If this were true, the major portion of the surge would be discharged through the customer's ground and might result in a higher meter-failure rate. This is borne out by table XVII which shows a low meter-failure rate for rural installations having a low ground resistance.

Frank Sanford (Cincinnati Gas and Electric Company, Cincinnati, Ohio): Perhaps the most important conclusion of this paper is that interconnection of grounding on distribution transformer installations is an established practice. The general data confirm the data that individual utilities have that this form of protection has accomplished a great deal and that its continuation and extension is justified. Three detailed comments may be noted:

1. The increase that is noted in the paper in grounding of the transformer tanks may be due more to the use of rural-type transformers rather than any change in policy on urban type installations.

2. The relationship between fusing schedule and per cent blown fuses caused by lightning is not shown in the paper. Its importance may justify a more detailed study and the economics of failure and service outages may justify a higher fuse schedule, especially on the smaller size transformers.

3. It would seem better not to group together all systems using one to five kv distribution, in comparing standard connection and interconnection. Of twenty companies, only four failed to show a large reduction in both transformer failures and fuses blown, with the interconnection method. Of these, one showed an increase in fuses blown but they operate with the arrester on transformer side of fuse and they may not fuse high enough for this condition. The other three operate a 4.8-kv delta system. Other records indicate a higher trouble experience with 4,150 volts or 4,800 volts than with the 2,400/4,150-volt system, other conditions being equivalent, and this would seem to justify the break-down of the records in comparison of this kind.

J. K. Hodnette (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Mr. L. G. Smith is to be complimented on the fine job he has done collecting and compiling the data on distribution transformer lightning protection. Data of this type should prove very valuable to distribution engineers in working out the problem of lightning protection to distribution transformers.

It is possible that some of the inconsistent results obtained to date could be explained if more were known of the operating conditions surrounding the transformers. It would be desirable to tabulate

the storm days per year experienced by each company reporting. In this manner the results obtained by different operating companies could be more accurately compared as well as the year to year results of individual companies.

It would be desirable to establish a more accurate nomenclature for the different methods of protection. Referring in particular to figure 8 in the paper which is designated as "three point protection," this phrase was originated by Mr. Fred Hanker to designate a type of protection in which the protective devices joined the high-voltage winding and low-voltage winding and the tank together, such as is illustrated in the author's figures 3, 5, 6, 7, 8, and 9. Since this interpretation is still in common use, a designation of a specific method of obtaining this result as three-point protection is somewhat confusing.

The results to date indicate that primary fuses may be expected to blow even though the protective device is connected ahead of the fuse link and presumably shunts the surge current around it. In my opinion this is due to (1) mechanical damage of the link; (2) short circuits attending storms; (3) surge currents flowing through the link together with associated secondary short circuits. Even though a protective device successfully shunts the major portion of the surge current around the fuse link, the charging current of the winding flows through the link. For steep front lightning surges this is by no means a negligible current and considering repetitive strokes the accumulative effect may be sufficient to blow the fuse link, particularly if the rating of the link is small. In addition to this effect, short circuits occur in the house wiring due to induced surges on the ungrounded secondary wires flashing over to grounded neutral. It is apparent that this condition cannot be eliminated and improvement in service can only be expected either by eliminating primary fuses or using large sizes.

C. F. Harding (Purdue University, Lafayette, Ind.): The principle and method of attack of this whole problem of protection of distribution systems may well be emphasized again. When first conceived the length of time and expense involved in its solution seemed prohibitive. One executive in the Middle West said it would take $50,000 and many years to get an answer to the interconnection problem if undertaken by statistical analysis of lightning discharges in natural thunderstorms in representative areas of several large cities.

As a predictive and foreshortened study, therefore, an experimental yet full-sized, four-span standard installation was made at Purdue University under the auspices of the Utilities Research Commission of Chicago whereupon thousands of induced surges were superimposed by means of a high-voltage laboratory surge generator. The results of these two years of testing of various types of interconnection and protection were reported at length in the AIEE TRANSACTIONS, March 1932, and in Bulletin No. 42 of the Engineering Experiment Station of Purdue University.

Since the solid interconnection was definitely proved by these tests to be most effective and since no dangerous excessive voltages appeared on the consumers' premises *if adequately low-resistance grounds were provided thereon*, many companies were encouraged to install such interconnections at a very much earlier date than would have been possible by the statistical field-study method. These predictions of the best methods of protection are well substantiated by the conclusions of this paper. Reports, during recent years, of large reductions in transformer burnouts, and of no trouble from excess potentials at the consumers' premises, after the interconnection was made, are confirmed by this paper and the resulting discussion thereon.

This general procedure, therefore, seems to justify the practical results and warrant the further consideration of laboratory methods of attack as co-operative projects between university research staffs and public utility and manufacturing corporations in order that the probable best solutions to such problems may be secured more promptly and with minimum of expense.

It is encouraging to note the very large increase in such interconnections during the last few years as well as the tendency to ground transformer cases and to reduce ground resistances on rural consumer circuits. The success that these changes have attained is a further confirmation of the worth of such full-sized laboratory tests. However, the limited number of meter burnouts may not necessarily be a criterion for indicating the correspondingly small number of cases of high potential on the consumers' premises as some types of meters, at least, will withstand relatively high surge potentials without burnout or serious change of calibration, the potential coils having sufficiently high inductance and such design as to permit flashover and the current coils having sufficiently low inductance and high carrying capacity to avoid damage due to heavy surge currents therein. The laboratory tests previously mentioned indicated that other consumer apparatus would flashover or burn out before meters would be damaged and that with house circuits closed and lamps lighted the attenuation of such surges was a worth-while safety factor.

J. R. North (The Commonwealth and Southern Corporation, Jackson, Mich.): Mr. Smith's paper presents a very considerable number of operating records covering the experience of different companies with distribution transformer protection from lightning. The conclusions reached should be very interesting to distribution engineers and others concerned with the application of protective equipment.

It would appear that the results of this study could be made more conclusive if it were possible to evaluate further the effects of:

(a). Number and severity of storms for the various locations.

(b). Age and relative insulation strength of the transformers involved.

(c). Relative protective characteristics of the lightning arresters.

The various methods of lightning protection of distribution transformers and the conclusions given are classified in the paper according to current terminology and by means of nine connection diagrams. As mentioned by Mr. Smith, it is difficult to compare the operating performance and the relative merits of the various schemes because of the lack of uniformity in nomenclature used throughout

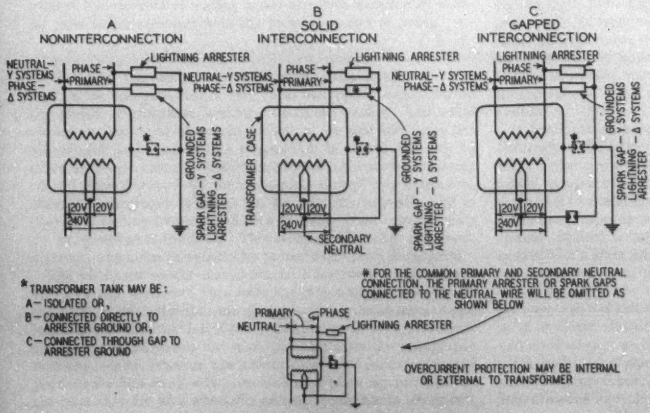


Figure 1. Distribution transformer protective schemes

the industry. Therefore, it would appear to be highly desirable to adopt a uniform and simple system of classification of the protective methods.

The lightning arrester subcommittee of the Institute's protective devices committee has given considerable thought to this, and figure 1 shows three diagrams illustrating all the connections commonly used for protecting distribution transformers. The three basic schemes of connections may be designated as (*A*) noninterconnection, (*B*) solid interconnection or (*C*) gapped interconnection, according to the connections of the ground leads of the primary protective devices and the secondary neutral. These leads may not be connected to the secondary neutral. They may be solidly connected or connected through a gap.

It will be seen from the notes on figure 1 that these three diagrams are applicable to all types of systems and schemes of connection. It is urged that some such uniform scheme of diagrams and terminology be adopted to avoid confusion and to eliminate lengthly descriptions of the various different protective schemes.

L. G. Smith: The suggestions made by Halperin, North, and Hodnette that the storm frequency for each year in each locality be weighted in determining the totalized data in the summary tables, might be misleading in that there is still another factor which cannot be determined, namely, storm severity. For example, on our own company system we have had years in which as many thunder storm days were experienced as in other years but the percentage troubles were materially lower due to variations in storm frequency. It is planned after five or six years' data have been obtained to weight the data supplied by each company by isoceraunic level for the territory for which the data was reported. Likewise the age and condition of the transformers involved should be considered as suggested by Andrews and North. However, in collecting data of this kind it is necessary not only to obtain from each company the numbers of transformers failing and number of primary fuses blown for each type of transformer but it is also necessary to know the number of transformers of each type on the system. If it was decided to obtain data in this amount of detail it is believed complete operating data would be obtained from only a few companies, as most companies do not keep their records in as much detail as would be required. It is believed that the obtaining of operating data on a large number of transformer installations will tend to average the effect of age and condition of transformers.

As Halperin suggests, the use of the solid interconnection is probably the best and cheapest means of lowering the ground resistance of the lightning arrester ground. Both Halperin and McMorris have discussed the effect of interconnection upon lightning arrester failures from two different points of view. While it is true as Halperin stated the effect of lowered ground resistance is to permit more surge current to pass through the arrester and hence probably result in more arrester failures, attention is called to the data in the McEachron and McMorris paper, which indicates that a very large percentage of the surges experienced on distribution systems are of lower current values than those which would cause arrester failures. It is also true that many failures of arresters even during storms may be due to other causes than high surge currents.

In reference to the poor performance of gapped interconnections as discussed by Halperin and Andrews it is quite possible that the voltage at which the gap breaks down is not materially different from the bushing flashover of the transformers protected. This is particularly true of the older types of transformers with smaller bushings. If such is the case it would be anticipated that the performance with the gapped interconnection would not be materially different from that with the standard connection in view of the fact that the flashover of the bushings results in effecting an interconnection with the secondary neutral. It is true as Andrews has mentioned that the rates of trouble are materially higher in rural districts. It is possible that the unexplained blowing of fuses mentioned by Andrews may be due to bushing flashovers or flashovers from the leads to the case that do not leave marks sufficiently to be distinguished by a subsequent inspection.

In reference to the relationship between the fusing schedule and the rate of primary fuses blown as discussed by Sanford, an attempt was made to correlate these two points in obtaining data. However, it is quite difficult to reduce a fusing schedule to a single statement. In summarizing the data an attempt was made to reduce all fusing schedules to a percentage basis. As Hodnette has suggested, from a theoretical standpoint at least the higher the fusing schedule the lower the probable rate of primary fuses blown.

Discussions

of AIEE Technical Papers Published Before Discussions Were Available

ON THIS and the following five pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

The Rating of Resistance-Welding Transformers

Discussion and author's closure of a paper by C. E. Heitman published on pages 125–30 of this volume (March section) and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 26, 1938.

D. I. Bohn (Aluminum Company of America, Pittsburgh, Pa.): I am in hopes that Mr. Heitman's excellent paper on this subject will provoke quite vigorous comments, not only from those in the welding-machine industry, but from users and power companies.

In my opinion a welding machine should have a dual electrical rating. Part of this rating should be that of the transformer only. It is not so important as to just what method is used to rate this transformer as long as it is agreed on. The second part of the welding machine rating should advise the electrical conditions of the machine as a whole. A spot welder for instance may have a transformer of a 100-kva rating defined in whatever method is agreed on. The machine itself however may be of such a design as to require a demand of 225 kva. The same transformer in another machine of different design may require a maximum demand of only 150 kva. It is quite obvious therefore that to rate the machine on the basis of the transformer alone is misleading to all concerned.

Inasmuch as the thing that makes the weld is amperage, the maximum available amperes at the point of weld should be given as part of the machine rating.

If all machines have ratings of this nature, the question as to whether a machine will do a certain job could be answered directly without the necessity of making rather extensive electrical or welding tests as are necessary with the present systems of rating.

L. G. Levoy (General Electric Company, Schenectady, N. Y.): The author has presented a very lucid and timely exposition on the subject of resistance welding transformer rating. The widespread application of electronic control in the past few years has necessitated more dependable information to enable the user to select the proper control. Either overestimating or underestimating control requirements from the name-plate ratings may cause considerable unnecessary expense. In the past the only safe way to determine the requirements has been to make actual measurements on the transformer involved. This often entails delay and inconvenience, which can be avoided by proper name-plate designation.

The resistance welder manufacturers know these requirements. For a variety of reasons, they have not placed this information on the name plate. Probably the chief reason for the absence of this information is that the user, in many cases, does not know the secondary current requirements for welds, in which cases this information is useless. Now, however, many users know these requirements and yet from the data on a welding machine name plate cannot determine the suitability for jobs where the current requirements are known. Many manufacturers furnish this information on request and probably will welcome a new sane standard for name-plate designations to be followed by all manufacturers.

In order to eliminate all ambiguity and enable the user to determine whether or not his requirements are within name-plate rating of the transformer, it is necessary to specify, in addition to the items listed by the author, the maximum allowable time over which the duty cycle may be averaged with the understanding that this average is to be taken to include the most severe duty cycle imposed. This time is intimately associated with the thermal time constant of the transformer. The question arises whenever the duty cycle is irregular and the transformer is working near its rated capacity. Since this characteristic will vary with each size and design of transformer, the maximum allowable averaging time for the most severe duty cycle should be stated on the name plate to protect both the manufacturer and user against unintentional overloading.

The author discusses the use of an autotransformer or a tapped primary winding for varying the secondary current. There is another practical method known as phase control, which eliminates the necessity and expense of supplying either an autotransformer or a tapped-primary winding. It is accomplished, with electronic control, by delaying the start of the period of conduction of each voltage wave beyond the power-factor angle of the welder. This permits a smooth, stepless variation of heat over the entire range. Ease and speed of adjustment has made this method popular with operators where frequent changes in heat are required on work of varying nature, or where the steps of current adjustment by the available taps are too large.

L. W. Clark (The Detroit Edison Company, Detroit, Mich.): Mr. Heitman deserves the thanks of all concerned with the welding industry for his comprehensive discussion of the fundamentals involved in properly rating resistance welding transformers. There is bound to be some disagreement as to the details of standardization and recommended name-plate data, but the author's logical presentation should be a great help in crystallizing the ideas of various interested groups with a resulting standardization valuable to everyone.

From the standpoint of those interested in providing an adequate power supply for resistance welders, both in the plant itself where the welders are located and also from the power system providing the service, there are two factors mentioned by the author which may be further emphasized. He clearly shows the value of reduced impedance drop in the transformer but only mentions the effect of the impedance of the secondary circuit and states that it is this impedance that constitutes the load on the transformer. Only a very small percentage of the total secondary impedance is actually accounted for in the weld itself, the bulk of it being found in the conducting path from the transformer to the weld. I believe that, particularly in large machines, further emphasis should be placed upon the importance of keeping the secondary circuit as compact and of as low an impedance as possible thereby showing definite savings in welding transformer size, required distribution facilities throughout the plant, and power demands drawn from the power system.

It hardly seems necessary to discuss this point but it is a fact that many of the large present-day flash and projection welders have much higher reactive losses than necessary, resulting in oversized supply equipment all along the line. Money spent in improved design will be repaid many times over in savings in expenditures for transformer capacity and distribution facilities. The amount of current required to make a good weld is pretty much of a fixed quantity for a given job, but the type of path provided for conducting the current from the welding transformer to the work can be varied. Some of the welder manufacturers may not have realized the importance of this factor, and it is hoped that new machines will be of improved electrical design, resulting in lower power demands and lower costs of service for the user.

On the subject of name-plate rating, it is highly desirable that when the transformer is part of a complete welding machine, the maximum instantaneous kilovolt-ampere demand be given, as recommended by the author. With the present practice of a name-plate rating

based on a 50-per-cent-duty cycle, there is no logical basis upon which to lay out an adequate supply system. It becomes necessary to "guess" that the instantaneous demand will be two to five times the name-plate rating which is certainly poor basic information upon which to authorize plant expenditures for serving new equipment. The maximum instantaneous demand with the transformer operating on the highest voltage tap should be incorporated as part of the standard name-plate data.

H. S. Hubbard (nonmember; General Electric Company, Pittsfield, Mass.): Mr. Heitman's paper is of timely interest to both the user and manufacturer of welding transformers. Certainly it is apparent that the subject of transformer ratings for this class of service should be given serious consideration and it is logical that this should follow other standard lines of equipment.

The 50-per-cent-duty cycle, so commonly used as a rating basis, has little bearing on the capability of a transformer to perform satisfactorily on duty cycles for other than which it was originally designed. While the theoretical equivalent rating for any other period of operation may be easily determined from this value, there are real practical limitations dependent upon the transformer characteristics, which may restrict the use of a particular unit for a specific application.

Above all, the manufacturer should know the maximum instantaneous load requirement and the maximum duty cycle at that load. This permits him to so proportion his design that reasonable values of resistance and reactance are obtained and to determine the thermal rating on an equivalent continuous basis.

It is desirable that reactance and resistance be considered separately rather than as combined impedance for the reason that with the low power factor in the usual type of welding circuit, the reactance component is more nearly in phase with the load current and consequently influences the regulation much more than the resistance component. Thus two similarly rated transformers having the same impedance value might vary considerably in the matter of regulation.

In specifying a definite impedance in per cent, it is assumed that the designer has full control over the governing factors. This is not always so and cases will arise where it is economically impractical to meet such requirements. Perhaps it would be best to state the impedance or reactance rather than limit it to a fixed value.

Two transformers of the same kilovolt-ampere rating, but with different secondary voltages might have the same impedance drop in volts, but in per cent would vary inversely with the actual voltage output. This it would seem, might penalize an ordinary satisfactory design, if limits are too closely restricted.

While the true ohmic value of the loop impedance is numerically low as stated in the paper, the per cent impedance is usually extremely high, approaching 100 per cent of the transformer voltage. The power component across the weld is a very small factor and the voltage rating of the transformer is consequently influenced largely by the inductance of welding circuit or loop. Thus it is of utmost importance that the voltage drop in any welding circuit be carefully determined before the kilovolt-ampere rating can be specified.

In the matter of temperature rise, would it not be consistent to limit this to the AIEE standards for whichever class of insulation is used in the transformer design, that is, for class *A*, 55 degrees centigrade; and for class *B*, 75 degrees centigrade.

In connection with the chairman's request for items which might profitably be studied by the committee, I would like to suggest that an effort be made to correlate existing data on "loop" inductance and the methods used to calculate this circuit. There appears to be a divergence of opinion in this regard and it is difficult to obtain consistent data which might be applied generally. This is particularly important for as mentioned earlier in this discussion, the voltage drop in the secondary circuit is the major determining factor in the selection of the proper transformer voltage and hence the kilovolt-ampere rating for a particular job.

Some time ago in co-operation with one of the equipment manufacturers, we made a brief study of the kilovolt-ampere requirements for various size loops and based on the data submitted, developed a simple family of graphs. Although largely empirical, we have found these curves quite useful as a reference and I am sure that a more thorough study of this particular problem would be generally helpful to the industry.

S. M. Humphrey (nonmember; Taylor-Winfield Corporation, Warren, Ohio): I do not believe that anything will be accomplished unless the AIEE can agree to adopt a standard method of rating which has a reasonable chance of being accepted by other organizations such as the manufacturers of resistance-welding equipment, and their customers. Fundamentally it does not make any particular difference what the system of rating is as long as it is based on sound engineering principles and is universally acceptable.

Since a very large percentage of purchasers and users of resistance welding equipment are not electrical engineers, in fact they are not conversant with electrical terms, but have been brought up to consider that a transformer with certain kilovolt-ampere name plate will stand about so much, it would not be at all practical to attempt at this time to suddenly change this name-plate figure and then attempt to explain that a 70-kva transformer is now the same as a 100-kva used to be.

For this reason I strongly recommend that the present system of rating based on a 50-per cent duty cycle be adopted as standard by the AIEE. This would be as equally understandable by electrical engineers as the 100-per cent duty cycle and in the eyes of many users would not constitute any change at all.

In order to completely specify the transformer, it seems to me it would also be worth while to specify what its rating should be on the low tap as well as the high tap.

In regards to per cent impedance, I believe the best system would be to actually specify the impedance on the name plate in all cases. I am not in favor of specifying both resistance and reactance since in most cases the impedance is sufficiently close for all practical calculations and, furthermore, the actual resistance is a small part of the impedance and also very difficult to measure without machining special short-circuiting members for that purpose.

In regard to the temperature rise, I believe it best to adopt the present standard of 55 degrees for class-*A* insulation, and 75 degrees to class-*B* insulation.

Regarding the cooling water required, it might also be worth while to specify what pressure is needed to obtain the required gallons per minute for cooling.

In regard to the machines, it is very difficult to specify on the machine name plate the maximum primary current which will be drawn. If this were done it would have to be specified with the lower knee in its raised position and with the shortest horns which the machine could use, and if this figure were then used as a basis for power installation and purchase of control equipment, it might burden the purchaser with a much more expensive installation than was required for the work to be done.

At the present moment the Taylor-Winfield Corporation are supplying with a portion of their standard machines complete curves covering both the primary and secondary currents for all possible geometrical combinations of the secondary circuit and will extend this service to cover their entire line of machines as soon as possible.

The use of electronic control has been mentioned here by one of the representatives of the General Electric Company. There is one fact regarding its use which I believe should be pointed out since it will have some bearing on the power company's problem, and that is that heat reduction by means of electronic control results in a higher root-mean-square primary current than is obtained if the current reduction is made by means of a tap transformer or autotransformer. The increase in root-mean-square value is accounted for entirely by harmonics due to the wave form obtained from electronic heat control. The fundamental component of the current is the same with either system on secondary current reduction.

The above comments should not be construed to mean that I am opposed to electronic control. I believe it to be a very valuable addition to resistance welding equipment and from actual use have found it to be as fine a means of welding-current control as has yet been devised.

G. S. Bernard (nonmember; Aluminum Company of America, Pittsburgh, Pa.): I certainly agree with Mr. Heitman in that the name-plate data now furnished on resistance-welding transformers is of little value to the user of this equipment. The use of a thermal equivalent continuous kilovolt-ampere rating based on the maximum continuous secondary current which can be drawn from the transformer without exceeding the safe operating temperature of the insulation materials employed and the maximum rated open-circuit voltage is a logical method of rating any transformer whether for continuous or intermittent duty.

In making use of this kilovolt-ampere rating as proposed by Mr. Heitman, we must not lose sight of the fact that the current delivered by the transformer and not the kilovolt-amperes delivered should be used as a basis to determine if any given loading is within the safe limits for a given transformer.

Thus, regardless of the secondary voltage which may be used to obtain the welding current, the thermal equivalent continuous kilovolt-amperes is obtained by multiplying the secondary current by the maximum rated open circuit secondary voltage and the square root of the duty cycle.

As an example, consider the 34.7-kilovolt-ampere transformer proposed by Mr. Heitman.

Suppose that we wish to find the maximum duty cycle at which each of the following welding loads could be supplied.

CASE I

Welding current = 10,000 amperes
Load impedance = 0.001 ohm

CASE II

Welding current = 10,000 amperes
Load impedance = 0.0005 ohm

CASE III

Welding current = 5,000 amperes
Load impedance = 0.001 ohm

CASE I

Open-circuit voltage required is:

$$V_1 = 10{,}000 \times 0.001 + 0.04 \times \frac{10{,}000}{3{,}000} \times 11.6 = 11.6 \text{ volts}$$

$$\frac{10{,}000 \times 11.6}{1{,}000} \times \sqrt{D_1} = 34.7 \text{ kva}$$

$$\sqrt{D_1} = 0.30,\ D_1 = 0.09 = 9.0 \text{ per cent}$$

CASE II

Open-circuit voltage required is:
$V_2 = 10{,}000 \times 0.0005 + 0.04 \times 10{,}000 \times 11.6 = 6.6$ volts.
But in calculating thermal equivalent continuous kilovolt-amperes we use the rated voltage

$$\frac{10{,}000 \times 11.6}{1{,}000} \times \sqrt{D_2} = 34.7 \text{ kva}$$

$$\sqrt{D_2} = 0.30,\ D_2 = 0.09 = 9.0 \text{ per cent}$$

CASE III

Open-circuit voltage required is:

$$V_3 = 5{,}000 \times 0.001 + 0.04 \times \frac{5{,}000}{3{,}000} \times 11.6 = 5.8 \text{ volts}$$

Again we use the rated secondary voltage

$$\frac{5{,}000 \times 11.6}{1{,}000} \times \sqrt{D_3} = 34.7 \text{ kva}$$

$$\sqrt{D_3} = 0.60,\ D_3 = 0.36 = 36 \text{ per cent}$$

The above calculations show the method of using the T.E.C. [thermally equivalent continuous] kilovolt-amperes in calculating safe loadings for welding transformers. Had we used the actual secondary voltage instead of the rated maximum voltage, we would have obtained duty cycles of 27 per cent for case II and 143 per cent for case III which, considering the currents used, are obviously incorrect.

In selecting the proper maximum open circuit secondary voltage to obtain a given secondary current, an allowance for voltage drop in the lines supplying the welder transformer must be made. Unless the welder happens to be located favorably with relation to a large source of power, it will not be economical to provide a voltage regulation better than 2 per cent based on the T.E.C. kilovolt-ampere rating or six per cent based on the maximum current demand during the weld. As this supply line impedance is comparable to the transformer impedance, it should be included in the calculations of open circuit secondary volts required.

The inclusion of this factor will indicate the use of open circuit voltages some six to ten per cent higher than those which would be used if only transformer and load impedance were considered. The transformer kilovolt-amperes required will also have to be increased in proportion to the increased secondary voltage.

F. H. Roby (Square D Company, Milwaukee, Wis.): Manufacturers and users of resistance welding control equipment welcome any standardization of the kind suggested in Mr. Heitman's paper entitled, "The Rating of Resistance Welding Transformers."

Although welding transformers presumably have heretofore been rated on a 50-per-cent-duty-cycle basis, it has been almost impossible to calculate the magnetic contactor load in amperes, because of widely varying transformer design. Contactor ratings are properly based upon the load current (primary of transformer), primary voltage, interruptions per unit of time and length of welding period. Of the four factors involved, the load current is the most important and least often determinable.

It is true that nearly all manufacturers of control equipment have conducted tests to fix values of currents that can be safely interrupted under given operating conditions but this data is useful only to the individual in possession of the transformer or welding machine performance characteristics. If sufficient information is not included as name-plate data on both transformers and machines, there is little hope that contactors will be successfully applied by any one except the manufacturer of the equipment.

If the standardization under discussion becomes effective and all concerned use it, then manufacturers of control equipment can publish contactor-rating data that will be helpful to all in the industry.

R. L. Briggs (nonmember; Thomson-Gibb Electric Welding Company, Lynn, Mass.): I agree in principle with the recommendations suggested in this paper. It should be possible for a user of resistance-welding equipment to determine the exact capabilities of his machine. He should know how much it is capable of doing and how rapidly it can be used. I should like, however, to take certain exceptions to his recommendations and statements.

In a great majority of cases finished machines never experience

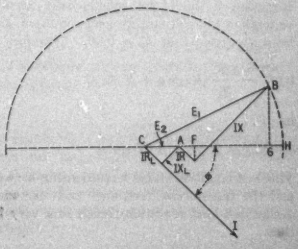


Figure 1

any changing of their transformers, portable spot welding equipment being practically the only exception. I therefore recommend that the complete welder be rated with the exception that the short-circuit impedance of the complete welder be stated rather than the per cent impedance at rated kilovolt-amperes. I also recommend that the method of rating suggested in this paper be applied to all transformers installed or to be used with portable welding equipment, with the exception that the six-per-cent value assigned as a standard for the percentage impedance be altered.

The value of six per cent suggested as a standard for the impedance drop does not seem consistent with the actual conditions involved in a resistance welding transformer. Consider figure 1 which shows the load vector diagram of a transformer referred to the secondary. Now

E_1 = open-circuit secondary voltage
E_2 = secondary voltage across load
I = load current
R_L = load resistance
X_L = load reactance
R = transformer resistance
X = transformer reactance
ϕ = current phase angle

By the definition of the impedance drop

$$Z_d = \frac{E_1 - E_2}{E_1} = \frac{\overline{AH}}{E_1} \tag{1}$$

But

$$\overline{AH} = \overline{AF} + \overline{FG} + \overline{GH} \tag{2}$$

$$\overline{AF} = IR \cos \phi \tag{3}$$

$$\overline{FG} = IX \sin \phi \tag{4}$$

The value of $\overline{GH}$ in a transformer is small in proportion to $\overline{AH}$ and this is true for all loads except at or near no load and for any power factor. Let us assume that $\overline{GH} = 0.2\overline{AH}$ as a maximum and use this value in our analysis.
Therefore

$$\overline{AH} - 0.2\overline{AH} = IR \cos \phi + IX \sin \phi \tag{5}$$

$$\overline{AH} = 1.25\ (IR \cos \phi + IX \sin \phi) \tag{6}$$

Now

$$Z_d = \frac{\overline{AH}}{E_1} = \frac{1.25}{E_1}\ (IR \cos \phi + IX \sin \phi)$$

$$= 1.25\ \frac{I}{E_1}\ (R \cos \phi + X \sin \phi) \tag{7}$$

But

$$\frac{E_1}{I} = Z_t \text{ the total impedance} \tag{8}$$

Hence

$$Z_d = \frac{1.25}{Z_t}\ (R \cos \phi + X \sin \phi) \tag{9}$$

Equation 9 should be substantially accurate for the thermally equivalent kilovolt-ampere load condition, and at this loading it has been suggested that $Z_d = 0.06$. Therefore

$$0.06 = \frac{1.25}{Z_t}\ (R \cos \phi + X \sin \phi) \tag{10}$$

or

$$0.048Z_t = R \cos \phi + X \sin \phi \tag{11}$$

This last equation states a relationship between the total impedance and the transformer resistance and reactance. If the transformer design and load conditions result in a very high power factor load, then

$$0.048Z_t = R \text{ approximately} \tag{12}$$

This is a condition closely met in actual practice and demonstrates that the $Z_d = 6$ per cent is a proper value for high-power-factor loads used with power transformers. If the transformer is a resistance-welding transformer and the loads are those met in resistance welding the power factor is low, and

$$0.048Z_t = 0.7R + 0.7X \text{ as an example} \tag{13}$$

This is a condition almost impossible to meet in actual practice. Actually the sum of the fractions of the transformer resistance and reactance in the case of butt welders may be $0.5Z_t$ which indicates that Z_d should approximately be 65 per cent for these types of welders. This value of Z_d must necessarily be different for the transformers used in the other types of welding machinery.

I therefore recommend that a value of Z_d be established for the welding transformer which is commensurate with the type of welder in which the transformer is to be installed. It is still my belief, however, that excepting the portable welding equipment it is better to use the short-circuit impedance data for the purpose of rating the welder complete rather than to rate the transformer proper in terms of its impedance drop at a specified loading.

C. E. Heitman: It is gratifying to the author to note the number of very pertinent discussions of this paper which indicate that there is considerable interest in, and desire for, standardization of welding transformer ratings. It is sincerely hoped that this paper and these discussions will stimulate further activity in this direction which will bear fruitful results.

The discussion by Mr. Bernard brings out two important points which I failed to stress in the paper. First, that in calculating the maximum permissible duty cycle, the maximum open-circuit secondary voltage should be used in conjunction with the thermally equivalent continuous kilovolt-amperes. However in this connection I should like to bring out one more point which some of you may have considered already. Referring to case II of Mr. Bernard's discussion, with an open-circuit voltage of 6.6 volts, the member of primary turns will be roughly twice that used in obtaining the maximum secondary voltage. The primary resistance will therefore be approximately twice, but for the same secondary current, 10,000 amperes, the primary current will be one-half. The primary heating will therefore be $(I/2)^2 \times 2R = \frac{1}{2} I^2R$ or one-half its previous value.

The secondary heating will of course be the same. The determination as to whether or not the transformer can stand a duty cycle higher than nine per cent will depend upon what percentage of the total copper loss is contributed by the primary winding. If the primary could contribute all the copper loss it is obvious that the duty cycle could be doubled in this case, since the core loss, per weld, is approximately one-fourth its previous value. However, since the present design tendency is to make the primary copper loss low, a reduction of 50 per cent in this factor will make very little difference in the total copper loss. However for most present-day designs, the duty cycle could be increased above nine per cent in case II, but for safety it is not desirable to do so. If the actual values of primary and secondary copper losses are known, an accurate determination of the maximum permissible duty cycle (somewhat above nine per cent) could be made.

Second, Mr. Bernard brings out the point that the impedance of the primary line feeding the transformer should be considered in calculating the open-circuit secondary voltage of the transformers.

Both of these considerations were omitted from my paper since I felt that they might be confusing in a discussion of transformer ratings. I furthermore felt that although the question of primary feeder impedance is very pertinent to resistance welding, it was not within the scope of this paper. It is a subject within itself and one which needs further discussion.

Regarding the question raised as to the maximum allowable time over which the duty cycle may be averaged, I feel that this can best be answered by the manufacturers. I am therefore suggesting that they offer recommendations in this connection, with the idea in mind that this information will not be included on the name plate, but

that values of time, depending upon the rating, or group of ratings, be given in the standards. For example, in transformers rated from 25 to 75 kva the duty cycle may be averaged over a certain period, whereas transformers rated from 75 to 150 kva may be averaged over a different time period. I recommend that the ratings be divided into such groups and a definite averaging time be assigned to each group and included in the standards, rather than adding this information to the name plate.

Mr. Hubbard's suggestion that the reactance and resistance be considered separately rather than as a combined impedance, is very pertinent. Such information would undoubtedly be desirable, if the manufacturers would agree to supply it. However, I feel that it is not essential. That a standard based on the assumption that the transformer impedance voltage is in phase with the load voltage, will take care of the worst condition, from a standpoint of regulation, and will therefore serve the purpose. If certain manufacturers desire to include this information on the name plate, or submit it to the customer in the form of a test report, I do not have any objections. However, in outlining standards such as these, I feel that the required name-plate information should be held to a minimum.

I am in hearty agreement with Mr. Hubbard's suggestion that the resistance welding committee make a study of existing data on loop impedances and methods used for calculating this data. I have certain data on this subject and I am sure many others connected with the art have likewise. A correlation of this data would prove most useful and beneficial to all concerned.

I am in partial agreement with Mr. Humphrey in that it does not make any appreciable difference what standard of rating is adopted, so long as it is technically sound and rigidly adhered to by the various manufacturers. From a technical standpoint, a rating based on a 50-per cent duty cycle is just as sound as one based on the continuous or 100-per cent duty cycle. I feel that the 100-per cent duty cycle rating is the most logical and I have recommended this for adoption as standard. However, if it is felt by all concerned that a standard rating based on a 50-per-cent-duty cycle will be more universally accepted and adhered to, I feel that this should be adopted.

In this connection I might add that in the discussion which followed the presentation of this paper, the suggestion was made that a standard be adopted which would keep the name-plate kilovolt-amperes as low as possible. Such a standard would obviously be based on a 100-per cent duty cycle. Rated on this basis a certain transformer might have a name-plate rating of 100 kva, whereas the same transformer if rated on the basis of a 50-per-cent duty cycle would have a name-plate rating of 141 kva.

I would like to express my further approval of Mr. Humphrey's suggestion that the required cooling be expressed in terms of water pressure required rather than in gallons per minute.

The thought expressed in Mr. Brigg's discussion has been mentioned before in certain verbal discussions which I have had with various interested parties. Mr. Briggs feels that it is not practical to obtain a transformer impedance as low as six per cent in units having a very low open-circuit secondary voltage. In the example he cites of a butt-welding transformer, the maximum open-circuit secondary voltage would be in the neighborhood of five volts. A normal impedance of six per cent would mean an impedance voltage drop of only 0.3 volts in the transformer. This, Mr. Briggs feels, is impractical to obtain. I think it best to abide by the advice and opinions of the various manufacturers in this matter, since through their experience, they are in a better position to state what they can obtain economically. I do know however that an impedance of six per cent can be obtained with an open-circuit secondary voltage of 15 volts in ratings up to 200 kva. To outline a group of standard impedances based on a kilovolt-ampere rating and open-circuit secondary voltage ranges might be too complicated for the purpose of standardization. It therefore seems desirable to omit from the standards any specification as to the quantitative value of the transformer impedance, but rather to require that the manufacturer state on the name plate, the value of the impedance, whatever it might be, at rated load. It will therefore be left to the judgment of the user to select the transformer having the lowest impedances, all other factors being equal.

Most of these discussions have been confined to items 5, 6, and 8 of my recommendations, and from them I am prompted to make the following changes in the recommendations:

Item 6 to read "Per cent impedance at rated kilovolt-amperes"

Item 8 to read "Type of cooling required (if water-cooled state required pressure at specified intake temperature)"

I will not revise item 5 at present, but if it is mutually agreed that a rating based on a 50-per-cent-duty cycle will be more satisfactory to all concerned, I will co-operate toward its adoption as standard.

In conclusion I should like to emphasize the fact that these standards, in order to be effective, must first of all be technically sound, and secondly universally accepted by all concerned. It is sincerely hoped that the manufacturers and the users of welding equipment will co-operate toward arriving at a standard that will meet these two conditions.

Recent Advances in Resistance Welding

Discussion and closure of a report of the subcommittee on resistance welding of the AIEE committee on electric welding published on pages 37–8 of this volume (January section) and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 26, 1938.

L. W. Clark (The Detroit Edison Company, Detroit, Mich.): The report mentions the increased use of large-size welders, with transformer ratings in excess of 1,000 kva not being uncommon. Where there are many such large welders in a single plant as is true in most automobile and accessory plants, the problem of providing an adequate plant distribution system for serving the welders becomes important. The system must allow only a minimum of voltage drop which means a low-reactance design capable of serving the extremely high-current, low-power-factor loads.

A low reactance bus system designed and installed during the past year by one such user of welders is a distinct advance along such lines and a short description would seem appropriate. The main section of bus consists of a four-inch standard copper tube surrounding an extra-heavy three-inch copper tube with "micarta" tubing insulation between. The outer conductor is grounded, doing away with the necessity for any bus supports or outer insulation. Taps are brought out from the inner conducting tube at six-foot intervals, at which point a maximum of four welder control contactors can be located. Branch busses, each consisting of a two-inch standard tube surrounding a one-and-one-quarter-inch extra-heavy tube, radiate from the main bus at intervals throughout the plant.

The main bus can transmit 1,000 amperes of 40-per-cent-power-factor 440-volt welding current, a distance of 800 feet with only one-per-cent voltage drop, and the branches can transmit the same current 300 feet with one-per-cent drop. Large welders with current swings of 3,000 and 4,000 amperes can thus be served at considerable distances from the supply transformers and not cause over three- or four-per cent voltage drop in the bus system.

One such bus system, fed by 1,500 kva of transformers, serves four floors of factory area with a maximum transmission distance to the furthest machine of about 300 feet. Another is laid out in the form of a loop with over 1,000 feet of bus for serving a large ground floor manufacturing space. There are a total of about 18,000 kva of various types and sizes of resistance welders operating in regular production from these two systems.

C. L. Pfeiffer: I wish to thank Mr. Clark for his description of a low-reactance bus system for large-capacity resistance-welding machines. The question of power supply has always been not only an important but a vexing one in resistance welding for both the user and power company and improvements along these lines are of vital interest to the industry.

An Electronic Arc-Length Monitor

Discussion and author's closure of a paper by Walther Richter published on pages 115–17 of this volume (March section) and presented for oral discussion at the electronics session of the winter convention, New York, N. Y., January 25, 1938.

J. E. Waugh (nonmember; General Electric Company, Schenectady, N. Y.): This discussion covers merely the scope of an "Electronic Arc-Length Monitor" and not the equipment involved.

A layman is very apt to infer that, if the monitor is set within proper limits for a given electrode and the arc length is maintained within these limits by the welding operator, the result will be a perfect weld. This would mean that at last the boiler code authorities had found an instrument to check the quality of the welds.

However, it is not necessarily true that good welds will be produced if the operator maintains an arc length within the monitor limits. It is possible to obtain correct arc-length indications from the monitor and still obtain a very unsatisfactory weld. Conversely, it is possible to obtain very erratic results with an arc length monitor and still produce a satisfactory weld-metal deposit.

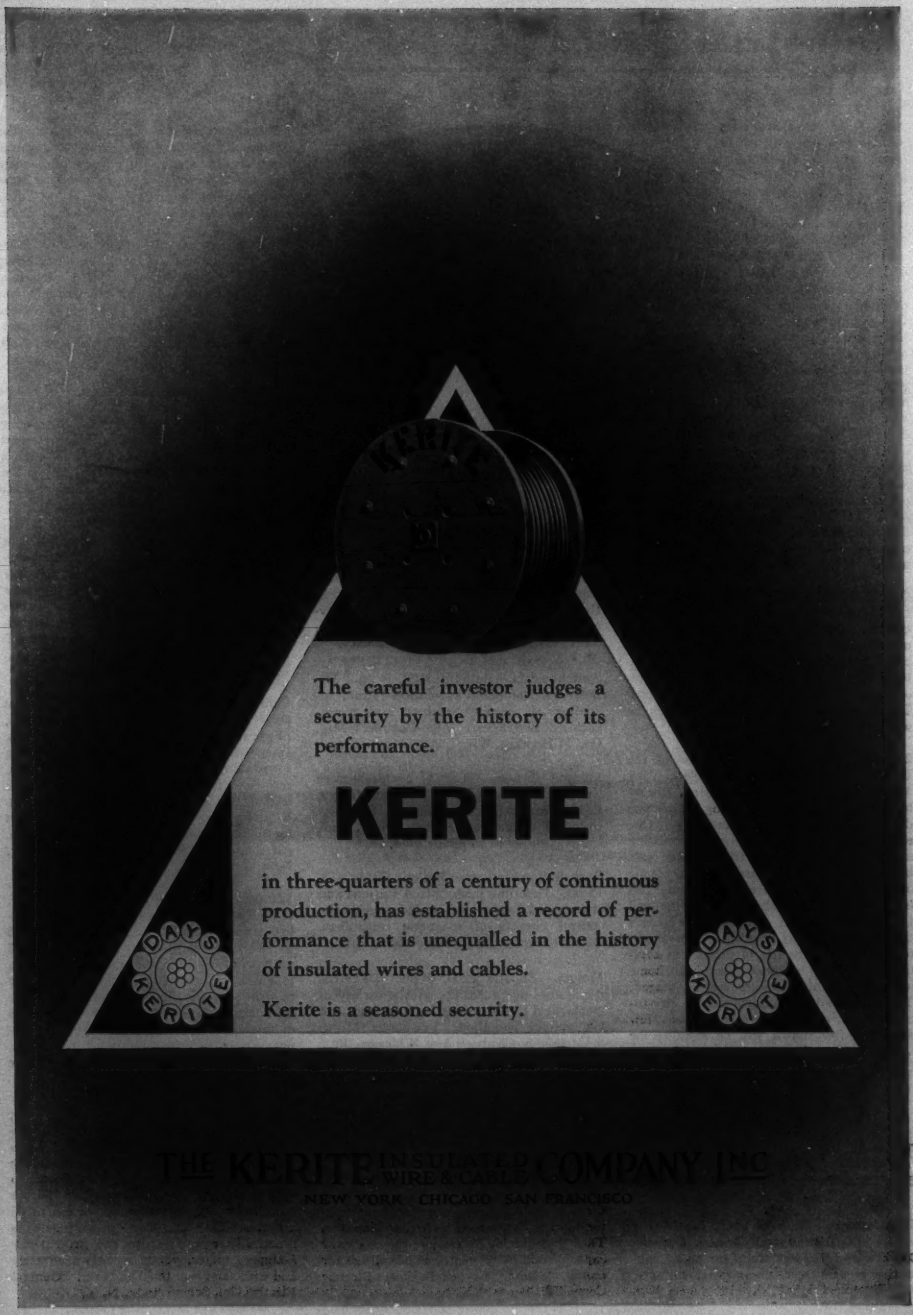
Under the first condition, one of the chief causes of weld defects is the failure on the part of the operator or automatic welding equipment to obtain proper fusion to the side walls of the joint being welded. The arc-length monitor will not indicate such a condition, since the operator can hold the correct arc length and still not direct the arc sufficiently against the side walls to obtain proper fusion.

In the second case, in making the first pass of a vertical fillet or butt weld, the operator must "whip" his electrode in and out of the molten pool in order to properly locate the weld metal. This condition will show very erratic indications on the monitor, yet the weld is perfectly sound.

Both of these conditions are very clearly shown on a recording voltmeter which we have used with the same purpose in mind as the monitor, namely, to predict the quality of the weld. An examination of many charts and the result of the physical tests forced us to reach the conclusion that we could not predict the quality of the weld from the chart readings.

From our point of view a monitor of the type described in Mr. Richter's paper would prove useful in training new men as welders, indicating to the man the correct voltage he should be maintaining. It should also prove valuable as an occasional check on production welders, but we feel that its general use, while acting as an aid toward improving the quality of the weld, could not represent a "cure-all" for weld defects.

Walther Richter: The instrument was never intended to predict the quality of the weld, since we know of course, that the arc voltage is only one factor of many affecting the quality of the weld. We therefore fully agree with Mr. Waugh that the use of the instrument cannot guarantee a perfect weld. But on the other hand, it is well known that various electrodes require different voltages for best results and it is clear that if the welder fails to use the proper voltage, an inferior weld will certainly be obtained. The instrument will in this case eliminate at least the possibility of a bad weld due to using the improper voltage, and therefore seems to render a worthwhile service. We feel that the instrument has great value in training men, checking up on their performance and in all cases where it is desirable or necessary to hold the arc voltage within close limits.


The careful investor judges a security by the history of its performance.
KERITE
in three-quarters of a century of continuous production, has established a record of performance that is unequalled in the history of insulated wires and cables.
Kerite is a seasoned security.
DAYS
KERITE
DAYS
KERITE
THE KERITE INSULATED WIRE & CABLE COMPANY INC
NEW YORK · CHICAGO · SAN FRANCISCO

Industrial Notes

More Oil-Electric Buses for Jersey.—With satisfactory performance definitely proven by a fleet of 29 oil-electric buses that have given more than 1,500,000 miles of service during the past year on its system, the Public Service Coordinated Transport is obtaining an additional 125 vehicles of this type. The buses will be built by the General Motors Truck & Coach Co., a division of Yellow Truck & Coach Mfg. Co. and will be equipped with electric motor and drive equipment developed by General Electric Company in cooperation with Public Service Coordinated Transport and Yellow-Coach engineers. As a further step in its modernization and expansion program, 83 more of the system's gas-electric buses are to be converted into the popular "all-service" vehicles at the company's own shops in Newark. These will be in addition to 44 other gas-electric buses in whjch the company is now installing General Electric all-service equipment. Public Service Coordinated Transport already has 456 vehicles of this type operating on 18 lines with 220 route-miles of overhead wires, and the new conversion program will bring the total number of all-service vehicles to 583.

United-Carr Fastener Appointment.—Lester W. Tarr will be in charge of the production and marketing of the new laminated phenolic insulation recently announced by the laboratories of the United-Carr Fastener Corporation. Mr. Tarr was previously general manager of the Continental-Diamond Fibre Company, with which he was associated for 12 years.

Bakelite Exhibit.—A large portion of the Bakelite Travelcade in the New York Museum of Science and Industry, Rockefeller Center, New York during March was devoted to the electrical industry. One exhibit showed the generation, transmission and consumption of electricity made safe by the use of resinoid varnishes and plastic insulators. Another traces a phone call from the time the receiver is picked up until the call is completed. Still another courses the path of a radio broadcast from studio to the home. The use of plastics in aviation, building, business machines, home furnishings, etc., is impressively staged. The Travelcade has started on a city-to-city tour for a period of two months in New Jersey. After that it will be installed for the remainder of the year in the Franklin Institute, Philadelphia, Pa.

Trade Literature

Transformers.—Bulletin 2289, 4 pp. Describes distribution transformers covering 200-kva and 150-kva units for small substation service in all commercial voltages. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Electric Tools.—Catalog, 56 pp. Describes a complete line of portable electric tools of all types. The Van Dorn Electric Tool Co., Towson, Md.

Transformers.—Bulletin GEA-2783, 4 pp. Describes outdoor current transformers designed for service on 34,500-volt circuits. General Electric Co., Schenectady, N. Y.

Rectifiers.—Bulletin B-2113, 12 pp. Describes Rectox rectifiers for changing alternating to direct current. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Automatic Service Restorers.—Bulletin 58, 8 pp. Describes automatic service restorers for rural distribution lines. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Bearings.—Catalog 380, 64 pp. Describes a wide range of sleeve type bearings, including over 200 sizes of motor bearings, individually illustrated. Johnson Bronze Co., New Castle, Pa.

Trip Attachment for Circuit Breakers.—Cat. 5, Sec. 5. Describes a new, type DTA, thermal-magnetic trip attachment for several types of air circuit breakers. Roller-Smith Co., 12 Park Pl., New York City.

Switchboards.—Bulletin 1190, 8 pp. Describes a complete switchboard line, including oil circuit breakers and metal-enclosed switchgear. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Relays.—Catalog D. A comprehensive treatment of relays for all purposes, timers, and thermostats is included in this new technical catalog. Struthers Dunn, Inc., 129 N. Juniper St., Philadelphia, Pa.

Push-Button Stations.—Bulletin GEA-2473, 12 pp. Describes push-button stations and other manual electric controls for use in the control circuits of magnetic controllers. General Electric Co., Schenectady, N. Y.

Motors.—Bulletin 2260, 8 pp. Describes d-c motors up to 200 hp, with a variety of mechanical modifications for both high and low voltage operation. Fairbanks, Morse & Co., 900 So. Wabash Ave., Chicago, Ill.

Low Voltage Generators. Bulletin 700, 4 pp. Describes low voltage generators and motor generator sets for electroplating and other electrolytic processes, from $\frac{1}{2}$ to 250 kw, 100 to 40,000 amperes, 6 to 60 volts. Columbia Electric Mfg. Co., Cleveland, O.

Circular Slide Rule.—Power factor calculator chart in the form of a circular slide rule. This chart quickly determines the necessary capacity and power-factor of capacitors for motor starting. Cornell-Dubilier Electric Corp., So. Plainfield, N. J.

Automatic Transfer Switches.—Bulletin, 20 pp. Describes various types of mechanically and magnetically held automatic transfer switches, remote control switches, relays, etc. Automatic Switch Co., 154 Grand St., New York City.

Ceramic Property Chart.—Outlines the characteristics and properties of ceramic insulating materials in concise and easily accessible form. These products are Steatite ceramics known as Alsimag and Lava. American Lava Corp., Chattanooga, Tenn.

Bakelite Laminated.—Bulletin, 48 pp. Describes laminated insulating materials bonded with Bakelite resinoid varnishes. Includes the forms in which the products are manufactured and gives in detail the respective properties and ranges of applications. Bakelite Corporation, 247 Park Ave., New York City.

Proving Rings.—Bulletin, 6 pp. Describes Olsen proving rings, for calibrating testing machines, in which the deflection of the ring when loaded along a diameter is measured by means of a micrometer screw and a vibrating reed mounted diametrically in the ring. Tinius Olsen Testing Machine Co., 500 No. 12th St., Philadelphia, Pa.

Current Regulators.—Cat. Sec. 60-552, 4 pp. Describes non-automatic constant current regulators for operating in an indoor substation and a fully automatic regulator for use in an unattended substation. Tables are included giving ratings, efficiencies, power factor and voltages for sizes from 5 to 70 kw. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Cable.—Bulletin C-41, 36 pp. Outlines the correct use of varnished cambric cable, physical properties and characteristics. Included are a series of new tables relating to recommended thickness of insulation, tests and new current capacities data for use of this cable in both air and ducts. Recommended instructions are also given for making straight joints on this type cable. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Voltage Regulator.—Bulletin DL48-71-F. A typical Raytheon voltage regulator stabilizes an a-c voltage that may vary from 95 to 130 volts and holds its constant at 115 volts plus or minus 1 per cent. It is a magnetic device without moving parts or adjustments, furnished to operate from any commercial a-c power source and deliver one or more required voltages with power outputs up to several thousand voltamperes. Raytheon Manufacturing Co., 149 Willow St., Waltham, Mass.

Watthour Meters.—Bulletin GEA-2721*A*, 16 pp. Describes the wide-limit, single-phase watthour meter, type 1-30. "Wide-limit" defines performance; for example, the 15 ampere meter has a load registration curve that practically falls on the 100 per cent line over the wide range of 0.5 to 60 amperes. Its light-load performance is practically equivalent to the present-day 5-ampere meter, yet it records accurately and with safety up to 60 amperes. General Electric Co., Schenectady, N. Y.

Photo Courtesy Boston Edison Company

Type 200-C: 850 va. 115-volt primary, 0 to 135 volts output at 7.5 amps. maximum. Type 200-CM (illustrated) Table Model: $17.50. Type 200-CU Panel Model: $14.50

Type 100-E: 2 kw. 115-volt primary, 0 to 115 volts output at 17 amps. maximum. $40.00. Type 100-L: 2 kw. 115- or 230-volt primary, 0 to 230 volts output at 8 amps. maximum. $40.00

SMOOTH CONTROL OF VOLTAGE

TYPICAL of the hundreds of uses for the General Radio VARIAC, the *continuously adjustable* autotransformer, is this application in which the Type 200-CM VARIAC is used in the primary of a high-voltage transformer across the secondary of which breakdown tests are run on oils, insulators, insulating gloves and cables.

This VARIAC provides absolutely stepless control of the high voltage *from zero* with a simple 320 degree rotary motion of the control knob. On a 115-volt circuit the Type 200-CM VARIAC supplies voltages from zero to 135 volts.

For under- and over-load tests on all types of electrical machinery and appliances the VARIAC is the ideal control. Inexpensive, rugged, with exceptionally low no-load losses and small full-load losses, VARIACS are finding wide application throughout the electrical industry.

Let us show you how the VARIAC can help you!

• WRITE FOR BULLETIN 259 FOR COMPLETE INFORMATION

GENERAL RADIO COMPANY

Cambridge, Massachusetts

BRANCHES: New York • Los Angeles

MANUFACTURERS OF PRECISION ELECTRICAL LABORATORY APPARATUS

New Products

Unique Electric Locomotive.—Built by the General Electric Company at its Erie (Pa.) works for the Semet-Solvay Company,

these locomotives, 16 feet high and only 15 feet long, will be used to haul cars of coke from the ovens to the quenching pit at the Great Lakes Steel plant, Detroit. What appears to be an outside fire escape circling three sides of the locomotive is an observer's platform.

Circuit Breakers Incorporate Metering.—At Wheeler Dam, each of seven 161-kv circuit breakers were required to have two transformers on one bushing. One is a silicon-iron 1200/5 multi-ratio transformer

for relaying; the other is a Hipernick iron-core transformer of high accuracy for metering. High voltage circuit breakers have for some time been called upon to supply energy for relaying, control, and metering through current transformers hung upon their bushings. However, these Westinghouse circuit breakers are perhaps the first to carry two transformers on one bushing.

Oil-Insoluble Insulating Compound.—An oil-resistant filler compound that will not flow at the usual cable-line operating temperatures and that is adequately fluid at the recommended pouring temperatures, has recently been developed by the General Electric Company. This material, No. 1332, is particularly suited to use in cable joints and terminals requiring a "solid" filler which must remain stable, physically and electrically, when in contact with insulating oils. By virtue of its oil-resisting qualities, this compound will retain its low dielectric power-factor characteristic and its physical permanence even under conditions that prove harmful to other compounds.

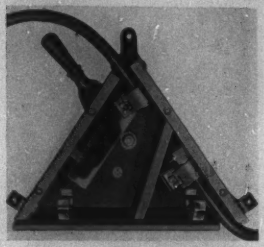
A-C Operated Oscillator.—A test oscillator completely new in design, featuring precision control both as to frequency and output level, has been introduced by the Weston Electrical Instrument Corp., Newark, N. J. The unit is equipped with a unique circuit providing automatic amplitude control at any required level from 1 microvolt to 100,000 microvolts. It is designed for high-stability operation from any 110–120 volt, 60-cycle, a-c line with output characteristics independent of fluctuations in line voltage. The direct-reading 330-degree dial, with six frequency scales averaging over a foot in length, is individually calibrated with hand-drawn scale divisions.

Four tubes are utilized in the circuit; a rectifier, the oscillator and amplitude control tube, a buffer and a modulator. Despite the wide range coverage in frequency and output level, the oscillator is sufficiently compact to be easily portable.

Prize Winning Wire Package Design.—The award voted to the Anaconda Wire & Cable Co. by the judges of "Modern Packaging's" 1937 package competition was based on the company's efforts in redesigning their 500-odd wire and cable packages. Whereas the principal consideration previously which determined the type of packaging was the ability of the package to carry the material safely to its destination, the redesign pro-

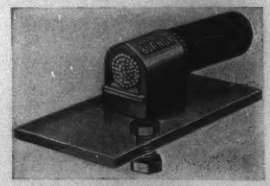
gram was approached with the objective of considering the convenience of the user first. Many changes were found necessary. The new design motif, created by Frank Condon, embodies the former color scheme of black and orange, and the well-established Anaconda spearhead trademark.

Safety Feeder Switch.—A new, inexpensive, low-capacity feeder safety switch has been designed by the Ohio Brass Co., Mansfield, O., to displace open type knife switch



installations in mines and industrial plants. The switch is of the quick-make, quick-break type, for 250–600 volts and is furnished in 300 and 400 ampere sizes. Enclosed in a fire-proof case it affords a safe means of disconnecting the circuit under load without danger to the operator or damage to the switch. A heavy rubber handle provides further protection. The action of connecting or disconnecting the switch is instantaneous and the quick-make feature insures a positive contact when the switch is closed.

Terminal for Current Transformers.—A new low cost clamp connector especially designed for terminating cables to the copper bars extending from each side of current transformers has been developed by the



Burndy Engineering Co., Inc., New York City. The clamp (type KPF) consists of a cast copper body through the bottom section of which a hole is tapped. A $\frac{1}{2}$-inch bolt passes through the hole in the copper bar and into the tapped body hole where it forces the pressure bar solidly against the cable. By tightening the nut assembled on the bolt, the joint is clamped to the bar and protected against vibration. The connector accommodates a range of cables and can be pivoted upon the bolt to permit cable tap-off at any angle from the bar.

Diesel Driven Arc Welder.—A new Diesel engine comparing favorably with gasoline engines in simplicity, weight and cost, as well as operating speed, has been adapted for driving arc welding generators by engineers of The Lincoln Electric Co., Cleveland, O., in collaboration with Diesel engine manufacturers. The arc welding generator employed is the 300-ampere "Shield Arc SAE" unit equipped with dual-continuous control which provides the right size and type of arc for each application.

VARNISHED Cambric Insulated Cables are showing superior advantages in many cases where loads have been increased. This type of insulation has the ability to withstand continuous high temperatures without deterioration, and it is not injured by contact with insulating or lubricating oils or greases. For these reasons it has become widely used for apparatus cables, and motor and generator leads where heat, high voltage and the effects of oil would shorten the life of rubber insulation.

American Steel & Wire Company Varnished Cambric Cables are available in either braided or lead sheathed insulation and are suitable for service up to 10,000 volts, and higher if lead sheathed or properly shielded.

For applications where heat resistance is of primary importance we have developed a special type of Varnished Cambric Cable which is even more resistant to continuous high temperatures than the standard type. Inquire about our "high-temperature" varnished cambric.

Loads have been increased and may be increased further. We will be glad to show you how our Varnished Cambric Cables can be of economical assistance to you.

VARNISHED CAMBRIC INSULATED CABLES

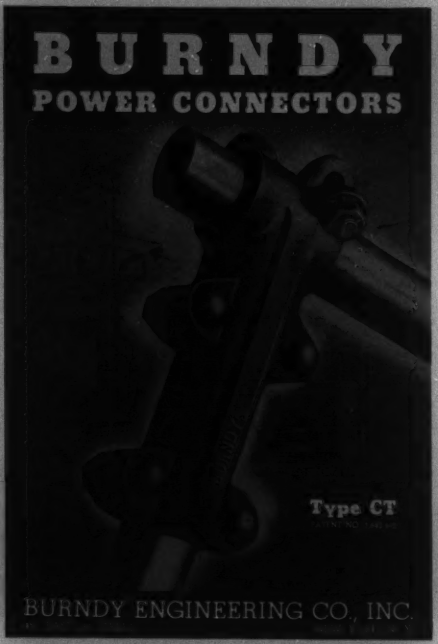
AMERICAN STEEL & WIRE COMPANY

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors* · United States Steel Products Company, New York, *Export Distributors*

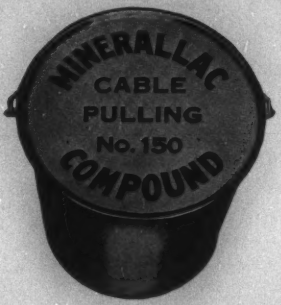
UNITED STATES STEEL

BURNDY
POWER CONNECTORS



BURNDY ENGINEERING CO., INC.

SAVE TIME on CABLE INSTALLATION by using

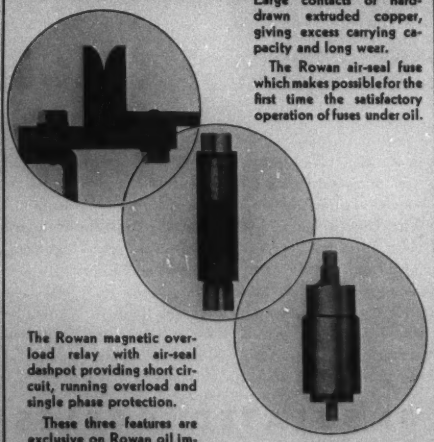


Lubricates the cable and conduit, eliminating wear and tear. Cuts down the time required to pull cable through the duct.

Ask for Bulletin No. 137

MINERALLAC ELECTRIC CO.
25 N. Peoria St. CHICAGO, ILL.

EXCLUSIVE FEATURES



Large contacts of hard-drawn extruded copper, giving excess carrying capacity and long wear.

The Rowan air-seal fuse which makes possible for the first time the satisfactory operation of fuses under oil.

The Rowan magnetic overload relay with air-seal dashpot providing short circuit, running overload and single phase protection.

These three features are exclusive on Rowan oil immersed control equipment. Complete data on request.

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

The Nation's Technical Employment Market

IS BROUGHT TO YOUR DOOR through the Engineering Societies Employment Service.

You do not have to take the "best you could get" from a limited local market.

You can procure the right man for the job by availing yourself of the service and resources that are proffered without cost to you. Send your requirements to

THE ENGINEERING SOCIETIES EMPLOYMENT SERVICE

NEW YORK . . . . . 33 West 39th Street
CHICAGO . . . . . 205 W. Wacker Drive
SAN FRANCISCO . . . . . 57 Post Street

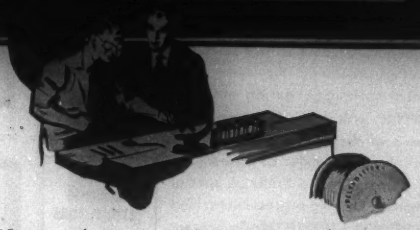
DELTABESTON WIRE

MAGNET WIRE • POWER CABLE

BOILER ROOM WIRE • CONTROL CABLE

STOVE WIRE • MOTOR LEAD CABLE

SWITCHBOARD WIRE • FIXTURE WIRE



PROGRESS...
WITH A PURPOSE

Deltabeston Conductors Built to Answer Your Requirements

There is a Deltabeston Wire and Cable for every application. Each has been built to exacting standards. Each is ready to answer your demands.

From the smallest Magnet Wire to the largest Power Cable, Deltabeston means dependability. It means a background of sound engineering — careful workmanship. It means a desire to build the best wire and cable possible — and doing it!

Constant engineering research has done a lot for Deltabeston dependability. It has brought about Purified Asbestos insulation, through a process that removes harmful impurities from the asbestos. It has perfected a method of felting the insulation, so that cracks and breaks are eliminated.

Next time you specify wire and cable, specify Deltabeston. *It will pay its way in extra service.* For complete information write to Section Y-8183, Appliance and Merchandise Department, General Electric Company, Bridgeport, Connecticut. Deltabeston Wires and Cables are distributed by General Electric Merchandise Distributors and Graybar Electric Company.

PURIFIED ASBESTOS INSULATION FOR HIGHER DIELECTRIC STRENGTH

COMPLETE RESISTANCE TO HEAT, MOISTURE AND OIL

GENERAL ELECTRIC

PREVENT GROUND FAILURES

-WITH THIS SLOT INSULATION THAT'S GOT EVERYTHING!

Everything you need in a slot insulation, you'll find in Manning papers. Because of their selected stock and carefully controlled processing, they have unusual **TOUGHNESS.** Natural shrinkage during manufacture gives them **STRETCH,** so that they do not tear when coils are pounded. Because of their **CHEMICAL PURITY,** Manning papers have longer life under continued heat and do not become brittle. A special mechanical finishing process insures high **DIELECTRIC STRENGTH.** To prevent ground failures, specify Manning papers.

MANNING 300—Highest quality non-chemical all-rag paper. Extremely tough. Superior heat aging qualities. All sheets are given an over-all dielectric test at 300 volts per mil.

MANNING B—Highest quality non-chemical 50% rag paper. Unusually tough. Good heat aging qualities. A superior paper at a lower price.

OTHER MANNING DISTRIBUTORS

Pittsburgh
Earl B. Beach Co.
Oliver Bldg.

St. Louis
Insulation, Inc.
2127 Pine St.

Los Angeles
C. D. LaMoree
1325 San Julian St.

San Francisco
C. D. LaMoree
1889 Mission St.

Seattle
C. D. LaMoree
305 First Ave., So.

Philadelphia
Staub-Towle Co.
18 W. Chelton Ave.

Boston
Ingalls-Cronin Co.
10 High St.

MANNING PAPERS

SEND FOR DATA SHEETS
"HOW TO SELECT SLOT INSULATING PAPER"

Insulation Manufacturers Corp.
565 W. Washington Blvd., Chicago
NAME.....
COMPANY..... TITLE.....
ADDRESS.....

National Distributors
INSULATION MANUFACTURERS CORP.
565 West Washington Blvd. Chicago, Illinois
1105 Leader Building Cleveland, Ohio
DETROIT • MILWAUKEE • MINNEAPOLIS • PEORIA

Be Right with OHMITE
Originators of All-Porcelain Vitreous-Enameled Rheostats
Each passing year further emphasizes the underlying sound design of OHMITE close-control rheostats. The all-porcelain, vitreous-enameled construction, and the use of copper-graphite brushes, which OHMITE pioneered on these small rheostats, has made it possible for innumerable electrical devices to remain in trouble-free service year after year. Available in single or tandem units with straight or tapered winding, in stock or special models to meet your specifications. Write us about your rheostat control problems, or send for Catalog 16.
Ohmite Manufacturing Co.
4842 West Flournoy Street, Chicago, U.S.A.
OHMITE

Science Abstracts

All electrical engineers actively engaged in the practice of their profession should subscribe to "Science Abstracts."

Published monthly by the Institution of Electrical Engineers, London, in association with the Physical Society of London, and with the cooperation of the American Institute of Electrical Engineers, the American Physical Society and the American Electrochemical Society, they constitute an invaluable reference library.

Through "Science Abstracts" engineers are enabled to keep in touch with engineering progress throughout the world, as one hundred and sixty publications, in various languages, are regularly searched and abstracted. "Science Abstracts" are published in two sections, as follows:

"A"—PHYSICS—deals with electricity, magnetism, light, heat, sound, astronomy, chemical physics.

"B"—ELECTRICAL ENGINEERING—deals with electrical plant, power transmission, traction, lighting, telegraphy, telephony, wireless telegraphy, prime movers, engineering materials, electrochemistry.

Through special arrangement, members of the A.I.E.E. may subscribe to "Science Abstracts" at the reduced rate of $5.00 for each section, and $10.00 for both. Rates to non-members are $9.00 for each section and $15.00 for both. Subscriptions should start with the January issue. The first volume was issued in 1898. Back numbers are available, and further information regarding these can be obtained upon application to P. F. Rowell, Secy., I.E.E., Savoy Place, Victoria Embankment, London, W. C. 2, England.

American Institute of Electrical Engineers
33 West 39th Street, New York

Engineer: Our Product Development Dept. has a 'wow' in the making—what we need now is a vibration proof relay that will work on 800 cycles—do you know where you can get one?

PA: Sure thing: Struthers Dunn specializes on just such problems. I'll get in touch with them at once.

And you can't do better than getting in touch with Struthers Dunn, too, if you have a problem requiring relays!

RELAYS by DUNCO

STRUTHERS DUNN, Inc.

129 N. Juniper St., Philadelphia, Pa.

Engineering Societies Library

A reference library for engineers—contains 150,000 volumes—receives over 1,300 technical journals and periodicals on all branches of engineering.

Searches are made upon engineering subjects, translations from foreign publications, photostats made, etc.

Books may be borrowed by members of the AIEE. For information address, The Engineering Societies Library, 33 West 39th St., New York.

At Your Service

STOP WATCHES

. . . SAVE many times their cost in motor control, time studies and tests of all kinds. MEYLAN stop watches are used by largest industries, universities, Bureau of Standards, Army and Navy, etc.

Get new 12-page folder showing some 40 styles, 1/5 to 1/100 of a sec., $7.50 to $75.00, pocket and wrist models, stands, time-study board, etc. No salesmen will call.

REPAIRS

for all makes of stop watches. Get estimate without obligation.

A.R. and J.E. MEYLAN

268 W. 40 ST., NEW YORK CITY

ROLLER-SMITH

ANNOUNCES

3" SQUARE

ALTERNATING AND DIRECT CURRENT

Ammeters, Milli-ammeters, Micro-ammeters, Radio Frequency Ammeters and Milli-ammeters; Voltmeters, Milli-voltmeters and Special Instruments. Types TA, TD, and TW. The line is most complete, comprising all ranges required in commercial and laboratory work. Case and base are black Bakelite.

These Types TA, TD and TW instruments are available also in round cases, 3½" diameter.

Types FA, FD and FW instruments, 4" diameter, are offered where a somewhat larger instrument is required.

Send for New Supplement 3 to Catalog AE-48

ROLLER-SMITH COMPANY

Electrical Measuring and Protective Apparatus

MAIN OFFICE 17 Park Place, New York — WORKS Bethlehem, Pa.

SALES AGENCIES IN PRINCIPAL CITIES IN U. S. A. AND CANADA

Professional Engineering Directory

For Consultants in Engineering and Allied Sciences

BLACK & VEATCH
Consulting Engineers
Water, Steam and Electric Power Investigations, Design, Supervision of Construction, Valuation and Tests
4706 Broadway KANSAS CITY, MO.

SARGENT & LUNDY
Incorporated
ENGINEERS
140 South Dearborn Street
CHICAGO, ILLINOIS

FRANK F. FOWLE & CO.
Electrical and Mechanical Engineers
35 East Wacker Drive CHICAGO

A card here will keep your name and specialized service constantly before 21,000 readers of this publication.

JACKSON & MORELAND
ENGINEERS
Public Utilities—Industrials
Railroad Electrification
Designs and Supervision—Valuations
Economic and Operating Reports
BOSTON NEW YORK

GEORGE T. SOUTHGATE
ELECTRICAL AND THERMAL ENGINEER
Consultant in
Apparatus, Process and Patent Matters
Office and Laboratory
114 East 32nd Street NEW YORK

To appear in the following issue, cards must be received not later than the 20th day of the month.

THE J. G. WHITE ENGINEERING CORPORATION
Engineers—Constructors
Oil Refineries and Pipe Lines,
Steam and Water Power Plants,
Transmission Systems, Hotels, Apartments,
Offices and Industrial Buildings, Railroads
80 BROAD STREET NEW YORK

Z. H. POLACHEK
Reg. Patent Attorney
Professional Engineer
PATENT—TRADE MARK SPECIALIST
Individual or Yearly Basis
1234 Broadway Phone
(At 31 St) NEW YORK Longacre 5-3088

J. W. WOPAT
Consulting Engineer
TELEPHONE ENGINEERING
Construction Supervision
Appraisals—Financial
Rate Investigations
303 East Berry St. Fort Wayne, Indiana

SANDERSON & PORTER
ENGINEERS
FINANCING—REORGANIZATION—DESIGN—CONSTRUCTION
of
INDUSTRIALS and PUBLIC UTILITIES
Chicago New York San Francisco

J. G. WRAY & CO.
Engineers
Utilities and Industrial Properties
Appraisals Construction Rate Surveys
Plans Organizations Estimates
Financial Investigations Management
105 West Adams St., Chicago

WHEN YOU
require technical advice—or
a solution to an engineering problem—
CONSULT THIS DIRECTORY

Employment Bulletin

Engineering Societies Employment Service

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

B.E., 34, married; 14 yrs exper in elec constr and maintenance. Desires pos with pwr or indus concern. Any location. E-207-382-C-S-San Francisco.

ACTIVELY ENGAGED CONSULTING ELEC ENGR with one day per week to spare in devpmt of devices, coil depts, patent research, etc., within 100 miles of NYC. E-208.

SUBSTATION DESIGNER, tech sch grad; indoor and outdoor substation layouts. Pwr and lt instal for indus plants. Ship draftg exper on lt, pwr and interior com. E-196.

ELEC ENGR AND DES, 43, Am. born. Grad recognized col in elec engrg. Exper in central and substation layout, checking, etc., all voltages up to 220 K.V. E-200.

EXPER ILLUM ENGR, age 28, M.S. in E.E., desires work in ltg des and tech promotion including popular talks and articles on any phase of the ltg field. E-201.

E.E., Prof license, married, 37, G.E. test, service shop and ry electrification exper; 5 yrs developing, installing elec eqpt for waterway locks and dams; interested in elec control systems. E-193.

DEVPMT ENGR, col grad; exper in the des of small, accurately machined parts; desires pos with mfg concern. E-194.

ELEC DEVPMT ENGR, age 34. Several patents. Can follow through from idea to finished product; 12 yrs exper: Calculations, designs, experimental work, reports—condensers, transf, voltage regulators, high voltage eqpt. E-205.

WANTED: Pos leading to sales. E.E., B.S., 26, Cooper Union, '36; 13 mos selling elec and mech instruments in NY, NJ, Conn. Prospects contacted: Plants, utilities, bldgs, etc. E-199.

B.S., '35, E.E., '36, Columbia Univ. Exper as asst engr and draftsman for mfg of radio coils. Desires pos as elec engr in electronic field. Location preferred, foreign. E-202.

E.E., B.S., 1937, honor student, Tau Beta Pi, single. Has had six mos lab exper. Prefers pos leading into devpmt work. Location immaterial. E-203.

Ech. E., B.S., Penn State. Jan 1938, single, 23; 14 mos exper with large chem corp as control laboratorian. Desires job involving electrolytic work. Location secondary. E-206.

E.E., 30, single; 10 yrs journeyman electrician and radiotrician, elec contracting field. Estimator, foreman, complete charge of wiring jobs. Shop exper repair elec machy, motors, radio service, pub address instal. E-198-382-C-2-San Francisco.

E.E., B.S., '34; 3 yrs exper including constr, maintenance, oprn and testg in pwr station. Desires pos in one of the above mentioned capacities. Location immaterial. Available immed. E-204.

ELEC ENGR, Univ Grad, exper in pub util distr, both overhead and underground lines, pwr stations and substations, desires pos in distr dept, either engg or oprtg duties. E-195.

ERECTING ENGR, 53. Specialized in complete instal of swbd and control systems, elec generating and substations, chem and indus plants; elec plant oprn and maintenance. E-197.

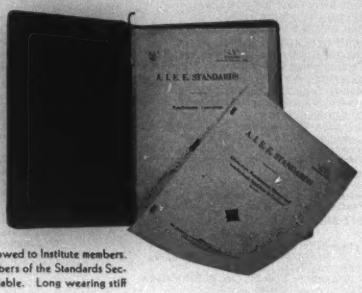
E.E., B.S., 1934, Lehigh, single, 27. One yr in research lab on direct coupled, other special amplifiers and assoc eqpt. Desires electronic pos, preferably research. Location immaterial, salary secondary. E-209.

ENGINEERING SOCIETIES EMPLOYMENT SERVICE

NEW YORK 31 W. 39th St. | SAN FRANCISCO 57 Post St. | CHICAGO 211 W. Wacker Dr.

A.I.E.E. STANDARDS

THE Standards of the American Institute of Electrical Engineers now comprise forty-seven sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members. Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available. Long wearing stiff covers, resembling leather, lettered in gold. Price $1.75 net.

(Figures in Parentheses Give Dates of Latest Editions)

No. 1	General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery (4-25)	$0.20
4	Measurement of Test Voltage in Dielectric Tests (5-28)	.30
*C50	Rotating Electrical Machinery, Supersedes Nos. 5, 7, 8, 9 and 10 (4-36)	1.30
*11	Railway Motors (4-37)	.50
*12	Constant Current Transformers (1-34)	.30
13	Transformers, Induction Regulators and Reactors (5-30)	.40
*14	Instrument Transformers (3-25)	.30
*15	Industrial Control Apparatus (5-28)	.40
*16	Railway Control Apparatus (1-33)	.40
*17f	Mathematical Symbols (2-28)	.30
*17g1	Letter Symbols for Electrical Quantities (11-28)	.20
*17g2	Graphical Symbols for Electric Power and Wiring (1-34)	.20
*17g3	Graphical Symbols for Radio (1-34)	.20
*17g5	Graphical Symbols for Electric Traction Including Railway Signaling (1-34)	.40
*17g6	Graphical Symbols for Telephone and Telegraph Use (3-29)	.20
*18	Capacitors (6-34)	.20
19	**Oil Circuit Breakers (3-38) (NEW)**	.40
20	Air Circuit Breakers (5-30)	.30
22	Disconnecting and Horn Gap Switches (7-25)	.30
*C37.1(23)	**Relays Associated with Power Switchgear (1937) (NEW)**	.40
*C37.2(26)	**Automatic Stations (1937) (NEW)**	.40
27	Switchboards and Switching Equipment for Power and Light (10-30)	.30
*28	Lightning Arresters (3-36)	.30
*30	Wires and Cables (4-37)	.40
33	Electrical Measuring Instruments (1-27)	.30
*36	Storage Batteries (2-28)	.20
*38	Electric Arc Welding Apparatus (1-34)	.40
*39	Electric Resistance Welding Apparatus (1-34)	.30
*41	Insulators (3-30)	.30
*42	Symbols for Electrical Equipment of Buildings (12-23)	.20
45	Recommended Practice for Electrical Installations on Shipboard (10-30)	1.50
*46	Hard Drawn Aluminum Conductors (6-27)	.20
*60	Specifications for Tinned Soft or Annealed Copper Wire. (See No. 61 for price.)	
*61	Specifications for Soft or Annealed Copper Wire. (Nos. 60 and 61 published as one pamphlet) (9-28)	.30
*C8.4	Specifications for 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
*C8.5	Specifications for Cotton Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.6	Specifications for Silk Covered Round Copper Magnet Wire. (See C8.7 for price.)	
*C8.7	Specifications for Enameled Round Copper Magnet Wire. (C8.5, 8.6 and 8.7 published as one pamphlet) (1936)	.30
*C8.11	Code Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
*C8.12	Cotton Braid for Insulated Wire and Cable for General Purposes (1935)	.20
*C8.16	Tree Wire Coverings (1936)	.20
*C8.17	Class OA 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes (1936)	.20
*C8.18	Weather Resistant Wire and Cable URC Type (1936)	.20
*72	Specifications for Weatherproof Wires and Cables. (See No. 73 for price.)	
*73	Specifications for Heat-Resisting Wires and Cables. (Nos. 72 and 73 published as one pamphlet) (9-32)	.20
100	Recommendations for the Operation of Transformers (6-30)	.20
500	Test Code for Polyphase Induction Machines (9-37)	.50
	Total Cost of Complete Set	$14.70

* *Approved as American Standard.*

SECTIONS IN PREPARATION

Six such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request. These sections are as follows:

No. 6	Mercury Arc Rectifiers.	40	Electrical Recording Instruments.
25	Fuses Above 600 Volts.	—	Test Code for Transformers.
501	Test Code for D-C Machines.	—	Test Code for Synchronous Machines.

American Institute of Electrical Engineers

33 West 39th Street New York

Advertised Products Index

AMMETER COMPENSATING COILS
Mineralac Electric Co., Chicago

AMMETERS VOLTMETERS
(See INSTRUMENTS, ELECTRICAL)

BATTERY CHARGING APPARATUS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

BUS BAR SUPPORTS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.

CABLE ACCESSORIES
Anaconda Wire & Cable Co., New York
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.
Mineralac Electric Co., Chicago

CAPACITORS
Aerovox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

CIRCUIT BREAKERS
Air-Enclosed
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Oil
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

CLAMPS, GUY & CABLE
Malleable Iron Fittings Co., Branford, Conn.

CONDENSERS, ELECTROSTATIC
Aerovox Corp., Brooklyn, N. Y.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh

CONDUIT PRODUCTS
General Electric Co., Bridgeport, Conn.

CONNECTORS, SOLDERLESS
Burndy Engg. Co., Inc., New York
General Electric Co., Schenectady, N. Y.

CONTROLLERS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore, Md.
Westinghouse E. & M. Co., E. Pittsburgh

CONVERTERS, SYNCHRONOUS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

DYNAMOS
(See GENERATORS AND MOTORS)

ELECTRONIC TUBES
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

GENERATORS AND MOTORS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

GROUND RODS
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.

INSTRUMENTS, ELECTRICAL
Graphic
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
Reeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Indicating
Ferranti Electric Inc., New York
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Integrating
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.
Scientific, Laboratory, Testing
Acme Elec. & Mfg. Co., Cuba, N. Y.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Leeds & Northrup Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.

INSULATING MATERIALS
Cloth
General Electric Co., Bridgeport, Conn.
Mineralac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh
Compounds
General Electric Co., Bridgeport, Conn.
Mineralac Electric Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh

INSULATING MATERIALS (*cont'd*)
Moulded
Bakelite Corp., New York
General Electric Co., Bridgeport, Conn.
Westinghouse E. & M. Co., E. Pittsburgh
Paper
General Electric Co., Bridgeport, Conn.
Insulation Manufacturers Corp., Chicago
Tape, Friction
Mineralac Electric Co., Chicago
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Westinghouse E. & M. Co., E. Pittsburgh
Varnishes
Bakelite Corp., New York
General Electric Co., Bridgeport, Conn.
Mineralac Electric Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

INSULATORS, PORCELAIN
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Westinghouse E. & M. Co., E. Pittsburgh

LIGHTNING ARRESTERS
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

LOAD RECORDERS—CONTROLLERS
Leeds & Northrup Co., Philadelphia

LOCOMOTIVES, ELECTRIC
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

METERS, ELECTRICAL
(See INSTRUMENTS, ELECTRICAL)

MOTORS
(See GENERATORS AND MOTORS)

POLE LINE HARDWARE
Malleable Iron Fittings Co., Branford, Conn.
Ohio Brass Co., Mansfield, O.

POLE MOUNTS
Malleable Iron Fittings Co., Branford, Conn.

RECTIFIERS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

REGULATORS, VOLTAGE
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

RELAYS
Dunn, Inc., Struthers, Philadelphia
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh
Weston Elec. Instrument Corp., Newark, N. J.

RESISTORS
Aerovox Corp., Brooklyn, N. Y.
Dunn, Inc., Struthers, Philadelphia
General Radio Co., Cambridge, Mass.
G-M Laboratories, Inc., Chicago
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
G-M Laboratories, Inc., Chicago
Ohmite Mfg. Co., Chicago
Westinghouse E. & M. Co., E. Pittsburgh

SHEETS, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh

SUB-STATIONS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.

SURGE ABSORBERS
Ferranti Electric, Inc., New York

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Mineralac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse E. & M. Co., E. Pittsburgh

SWITCHES GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Allis-Chalmers Mfg. Co., Milwaukee
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Westinghouse E. & M. Co., E. Pittsburgh

TURBINE GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

TURBINES
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

WATCHES, STOP
Meylan, A. R. & J. E., New York

WELDERS, ARC
General Electric Co., Schenectady, N. Y.
Westinghouse E. & M. Co., E. Pittsburgh

WELDING WIRE
American Steel & Wire Co., Chicago
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weatherproof
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Sleep SOUNDLY, LITTLE LADY

"Mother and Daddy are near and the telephone is always close by. It doesn't go to sleep. All through the night it stands guard over you and millions of other little girls and boys."

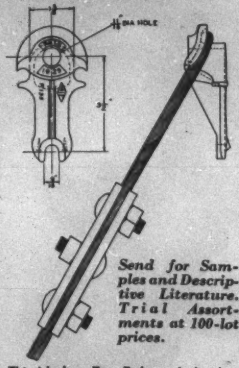
EACH NIGHT about 11,000,000 telephone calls are made over the Bell System. Many are caused by sudden, urgent needs.

Great in its every-day values, the telephone becomes priceless in emergencies. The constant aim of the Bell System is to give you, at all times, the best and the most telephone service at the lowest possible cost.

BELL TELEPHONE SYSTEM

M. I. F. Through-bolt Guying Specialties

Led by the M. I. F. Through-bolt Guy Hooks, these Guying Specialties are now being used from Maine to California and from Canada to Mexico, with relatively few gaps, by the leading Light and Power Companies. They are specified also for R. E. A. guying.



Guy Hooks—The P 135 type illustrated is for R. E. A. projects and other light construction. Rated for 13,000 lb. strand on ⅝" through-bolt. Priced at $15.60/C, F. O. B. Branford, and *lower in quantity*. P 134 Guy Hook for mounting on crossarm is rated at 10,000 lbs. as there is no supporting leg. Larger P 133 Guy Hook, rated at 16,000 lbs. on ⅝" bolt and at 20,000 lbs. on ¾" bolt, is type of most universal application. Still larger P 132 Guy Hook, rated at over 35,000 lbs. on 1" bolt may be installed with second through-bolt, thereby increasing capacity. Sometimes used for two ⅜" guys at corners. Where stresses are placed on poles by attachments to through-bolts, then the same through-bolts should logically be used for attaching the guys by means of Guy Hooks.

Send for Samples and Descriptive Literature. Trial Assortments at 100-lot prices.

Eye Nuts and Anchor Rods—P 128 Thimbleless ⅝" Eye Nut now priced at $12.60/C is being used by most Companies using these Guy Hooks. Also furnished assembled on high-strength steel rods as Thimble-less Eye Bolts and Anchor Rods at attractive prices. Larger sizes, Bolt Eyes, and Double Eye Nuts also available.

Curved Washers—The most complete line available anywhere from P 143, 3" x 3" at $6.60 /C up to P 119, 6" x 6" at $42.00/C. *All prices lower for larger quantities.*

MALLEABLE IRON FITTINGS COMPANY
Pole Hardware Dept. [Factory and New England Sales Office] Branford, Connecticut
New York Sales Offices Thirty Church Street
Canadian Mfg. Distributors
LINE & CABLE ACCESSORIES, Ltd., Toronto

DETACH HERE

A.I.E.E. MEMBERSHIP

To the National Secretary, A.I.E.E.
33 West 39th Street,
New York, N. Y.

_____ Date

The following persons are, in my opinion, qualified to become members of the Institute, and I recommend that they be furnished with application blanks and other pertinent information.

_____
NAME (please print)

_____
Position and Company Address

_____

* * *

_____
NAME (please print)

_____
Position and Company Address

_____

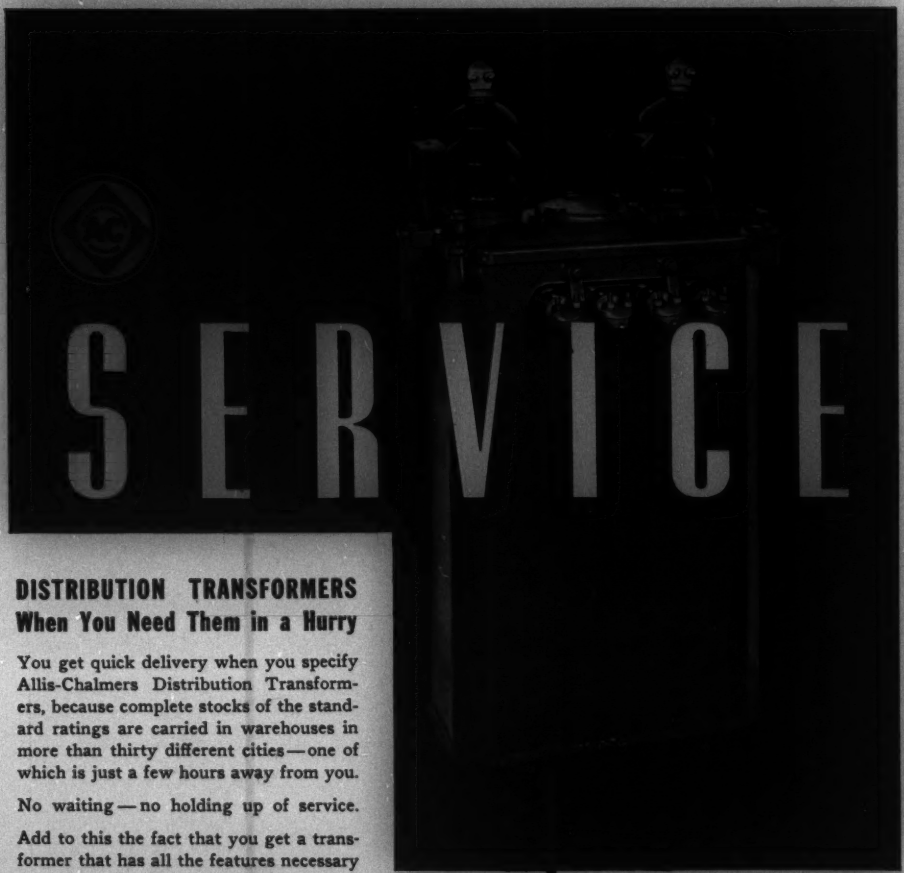
* * *

_____
SIGNED

_____
ADDRESS

INDEX TO ADVERTISERS

	Page
Allis-Chalmers Mfg. Co.	3rd Cover
Aluminum Co. of America	3
American Steel & Wire Co.	9
American Tel. & Tel. Co.	17
Black & Veatch	14
Burndy Engineering Co., Inc.	10
Dunn, Inc., Struthers	13
Engineering Directory	14
Engg. Soc. Employ. Service	10, 14
Engg. Soc. Library	13
Ferranti Electric, Inc.	4
Fowle & Company, Frank F.	14
General Electric Co.	2nd Cover, 11
General Radio Co.	7
Industrial Notes	6
Insulation Manufacturers Corp.	12
Jackson & Moreland	14
Kerite Ins. Wire & Cable Co. Inc.	5
Malleable Iron Fittings Co.	18
Membership Proposal Form	18
Meylan, A. R. & J. E.	13
Minerallac Electric Co.	10
New Products	8
Ohio Brass Company	1
Ohmite Manufacturing Co.	12
Okonite Company, The	4th Cover
Polachek, Z. H.	14
Roller-Smith Co.	13
Rowan Controller Co.	10
Sanderson & Porter	14
Sargent & Lundy, Inc.	14
Science Abstracts	12
Southgate, George T.	14
Standards of AIEE	15
United States Steel Corp. Subsidiary	9
Weston Elec. Instrument Corp.	2
White Engg. Corp., The J. G.	14
Wopat, J. W.	14
Wray & Co., J. G.	14



DISTRIBUTION TRANSFORMERS
When You Need Them in a Hurry

You get quick delivery when you specify Allis-Chalmers Distribution Transformers, because complete stocks of the standard ratings are carried in warehouses in more than thirty different cities—one of which is just a few hours away from you.

No waiting—no holding up of service.

Add to this the fact that you get a transformer that has all the features necessary for better distribution performance with high efficiency at lower maintenance cost.

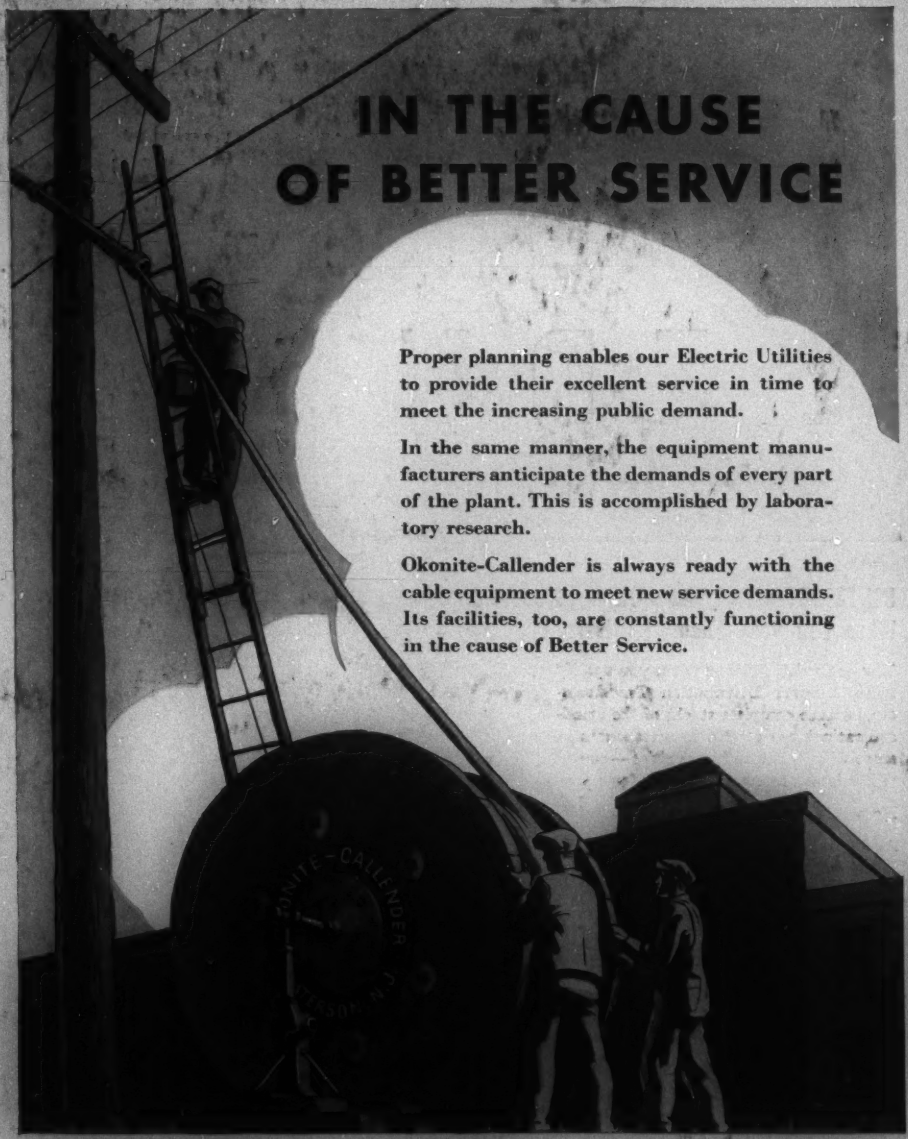
Informed engineers choose Allis-Chalmers Distribution Transformers because they have an enviable reputation for reliability, efficiency and economy of operation... and they are at hand when needed.

Send for descriptive literature describing in detail the advantages of using Allis-Chalmers Distribution Transformers.

TRANSFORMER DIVISION

ALLIS-CHALMERS

MILWAUKEE · WISCONSIN



IN THE CAUSE OF BETTER SERVICE

Proper planning enables our Electric Utilities to provide their excellent service in time to meet the increasing public demand.

In the same manner, the equipment manufacturers anticipate the demands of every part of the plant. This is accomplished by laboratory research.

Okonite-Callender is always ready with the cable equipment to meet new service demands. Its facilities, too, are constantly functioning in the cause of Better Service.

THE OKONITE-CALLENDER CABLE CO., INC.

AN AFFILIATE OF THE OKONITE CO.
Executive Office: Passaic, New Jersey

OKONITE QUALITY CANNOT BE WRITTEN INTO A SPECIFICATION